A geological and geochronological study of the Ryoke metamorphic terrain in the Kinki district, Japan(Dissertation_全文)

Ishizaka, Kyoichi

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学位授与申請者

石坂恭一

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主論文

A Geological and Geochronological Study of the Ryoke Metamorphic Terrain in the Kinki District, Japan

Kyoichi Ishizaka

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I

Abstract

In the first part of the present paper, the geology of the western marginal part of the Ryoke metamorphic terrain in the Kinki district is described, and in the second part, the geochronology of the Ryoke metamorphic terrain in the Kinki district is discussed.

The investigated area, located in Osaka and Nara Prefecture, consists almost entirely of granitic rocks. Metamorphic rocks derived from sediments develop only poorly in this area. The geological structure is monoclinal, i.e., northward dipping throughout the western part of the metamorphic terrain. Katsuragi granodiorite, which is non-foliated and quite homogeneous body, may represent the core part of the metamorphic terrain in the studied area. The genesis of microcline phenocrysts of porphyritic adamellite and sheared rocks in the southern part of the studied area are discussed.

The Rb-Sr and K-Ar age determinations were carried out on samples of biotite, muscovite, microcline and hornblende from the Ryoke metamorphic terrain in the Kinki district. 24 samples of granitic rocks, pegmatites and banded gneisses were collected mainly from the western part of the terrain. The results obtained in this study suggests that the metamorphism and plutonic activity in the Ryoke metamorphic terrain had continued almost throughout the Cretaceous period ranging from 130 m.y. to 70 m.y., culminating 110-90 m.y. The Rb-Sr ages on biotites of granitic rocks are well converged to 110-90 m.y. No great difference had existed in the time of the emplacement among the granitic rocks in this metamorphic terrain. The Rb-Sr ages on pegmatites are 90-70 m.y., which suggest that the metamorphism and plutonic activity in the terrain ended approximately 90-70 m.y. ago. The K-Ar and Rb-Sr ages on banded gneisses revealed quite discordant age pattern, which is discussed in detail.

Introduction

The age of the metamorphism, which produced the Ryoke and the Sambagawa metamorphic terrain, has been the subject of recent investigations. There have been hot disputes among geologists as to the time of the metamorphism of the Ryoke and the Sambagawa metamorphic terrain. Two sharply opposed opinions have been prevailing:

Kobayashi (1941) considered that the Ryoke metamorphism had occurred in a certain stage in his "Sakawa Orogenic Cycle", which ranged from middle Jurassic to middle Cretaceous. On the other hand, Yamashita(1957) and others considered that the metamorphism took place in late Palaeozoic or early Mesozoic era. Recently, K-Ar age determinations on several granitic rocks in the Ryoke metamorphic terrain have been reported. But no Rb-Sr age measurements which utilize the radioactive decay of Rb^{87} to Sr^{87} have been made so far.

The author has been studying the geology of the western part of the Ryoke metamorphic terrain in the Kinki district. In 1962, a mass spectrometer for geological age determination was loaned, on a long term, to the Geological and Mineralogical Institute, Kyoto University, through the courtesy of the Department of Terrestrial Magnetism, Carnegie Institution of Washington. Dr. L.T.Aldrich of D.T.M. visited the Institute and the geochronological work begun in this year.

The author has collected the samples used in this study from the Ryoke metamorphic terrain in the Kinki district, mainly from the western part of the terrain where he had been engaged in his field work. Recently, by Yoshizawa et al. the geology of the Ryoke metamorphic terrain in the Kinki district has been studied in detail. This geochronological study, by the author, has been carried out along with this geological study.

This paper will describe the geology of the western part of the Ryoke metamorphic terrain and state the geochronological study of the metamorphic and granitic rocks in the Ryoke metamorphic terrain, in the Kinki district.

Part I A geological study of the western part of the Ryoke metamorphic terrain in the Kinki district

I Outline of the geology of the Ryoke metamorphic terrain in the Kinki district

Little has been known so far as to the Ryoke metamorphic terrain in the Kinki district. Only the Kasagi and Mitsue area were studied in detail in the past. Recently, Yoshizawa et al. have made a detailed study of this terrain in the Kinki district and have made clear the geology and the geological structure of this district(1965b). The author has studied the geology of the western part of this district, which will be described in this paper. The geology of the Ryoke metamorphic terrain in the Kinki district as a whole is only briefly reviewed. Full details of the geology of this district will be given elsewhere.[34]

In the Kinki district, the Ryoke metamorphic terrain runs nearly E-W. The western and eastern extensions are interrupted respectively by Osaka bay and Ise bay. Its northern margin grades into the unmetamorphosed Palaeozoic strata or into the so-called "Cretaceous granite", and the southern margin is bordered by the Sambagawa metamorphic terrain with a thrust fault zone called "Median Tectonic Zone", although in some parts covered unconformably by the Izumi group which is upper Cretaceous in age. The metamorphic terrain consists of a mountain block, continuing from Mie to Nara Prefecture. This mountain block, however, is separated by Nara basin from that situated in Osaka Prefecture, as is shown in Fig. 1.

In the Kinki district as a whole granitic rocks occupy a large part of this metamorphic terrain. In general, metamorphic rocks derived from sediments are abundant in the eastern part and fairly scanty in the western part.

The metamorphic rocks comprise meta norite, metadiabase and various metamorphic rocks derived from the Palaeozoic sediments such as shale, muddy sandstone, chert, schalstein, small amount of calcareous rocks and tuff of biotite andesitic nature.

Among these, metanorite and metadiabase, presumably derived from norite and diabase which intruded into the Palaeozoic strata, are considered to represent the oldest igneous rocks in this district. Pelitic metamorphic rocks range from almost unmetamorphosed biotite-bearing slate to highly metamorphosed sillimanite gneiss through schistose hornfels.

The granitic rocks in this district can be classified into two groups. Distinct difference in geological structure is recognized between these two granitic rocks.

Group I, is usually accompanied by metamorphic rocks and is in subconcordant relation to the structure of metamorphic rocks; gneissose granodiorite and fine-grained granite belong to this group.

Group II, is discordant with the metamorphic rocks and the granitic rocks of Group I in structure; it cuts clearly the structure of the metamorphic rocks and the granitic rocks of Group I. A very large granite body called "Yagyu granite"emplaced in a basin-shaped batholith and located in the northwestern part of Ueno City. is a typical example of this group.

The granite equivalent to the Yagyu granite develops widely in the Ryoke metamorphic terrain. The Yagyu granite seems to grade into the "Cretaceous granite" which is distributed widely in the Tamba Zone (unmetamorphosed Palaeozoic formation), although the "Cretaceous granite" has been considered to have no relationship with the granitic rocks in the Ryoke metamorphic terrain.

The geological structure in this district may be summarized as follows: The structure of metamorphic rocks of sedimentary origin, gneissose granodiorite and also fine-grained granite are considered to preserve the original structure of this metamorphic terrain. Judging from the structure of these rocks, the following geological structure is considered; several synclines and anticlines which trend approximately E-W, are observed in the Kinki district, mainly in the central and eastern part.

These anticlines and synclines join together into a large anticlinolium. On both wings of this anticlinolium, metanorite and gneissose granodiorite are distributed. A large dome-shaped fine-grained granite body is located nearly on the axis of the anticlinolium.

The axis of this anticlinolium plunges into Osaka bay in the west and into Ise bay in the east. This means that there is another anticline, trending in N-S direction, in the central part of the Kinki Ryoke metamorphic terrain.

II Geology of the western part of the Ryoke metamorphic terrain in the Kinki district*

This area is situated in the east of the Osaka plain, constitutes the mountain range from Mt.Katano to Mt.Kongo and is the western marginal part of the Ryoke metamorphic terrain in the Kinki district. It constitutes an isolated mountain range, nearly trending in N-S direction. Except for the southern part, this mountain range is isolated by the Nara basin from the "Yamato plateau" which consists of the Ryoke metamorphic terrain.

Concerning this district, no systematic geological study has been conducted. The author has studied the geology of this area, mainly on the granitic rocks of the Mt.Katsuragi- Mt.Kongo area. This area, from Mt.Katano to Mt. Kongo, is composed almost entirely of granitic rocks and is extremely scanty of metamorphic rocks of sedimentary origin. This is the most striking characteristic of this area, compared with other areas in the Kinki district, where a fairly large amount of metamorphic rocks of sedimentary origin develops. An isolated banded gneiss block is situated in the southeast of Mt. Ikoma, constitutes the Mt.Matsuo mountain block and is the only metamorphic sedimentary rock mass in the studied area.

Two kinds of granitic rocks, as stated previously, can also be recognized in this area, judging from their rock facies. The granitic rocks distributed in the Mt.Katano-Mt.Ikoma area are considered to represent Group II, whereas the gneissose granodiorite and granodiorite in the southern part of the studied area may belong to Group I.

The porphyritic adamellite which is considered to have been formed by metasomatism develops in the south of Mt.Nijo. The granodiorite in the Mt.Kongo area has suffered considerable shearings, resulting in the formation of various kinds of sheared rocks.

The general geology of the investigated area will be described, with special reference to the genesis of microcline phenocrysts in the porphyritic adamellite and to the sheared rocks.

i Mt.Katano- Mt.Nijo area

In the northern part of this area, a large body of biotite granite is distributed and in the southern part, several kinds of granitic rocks, metamorphic rocks and volcanic rocks develop.

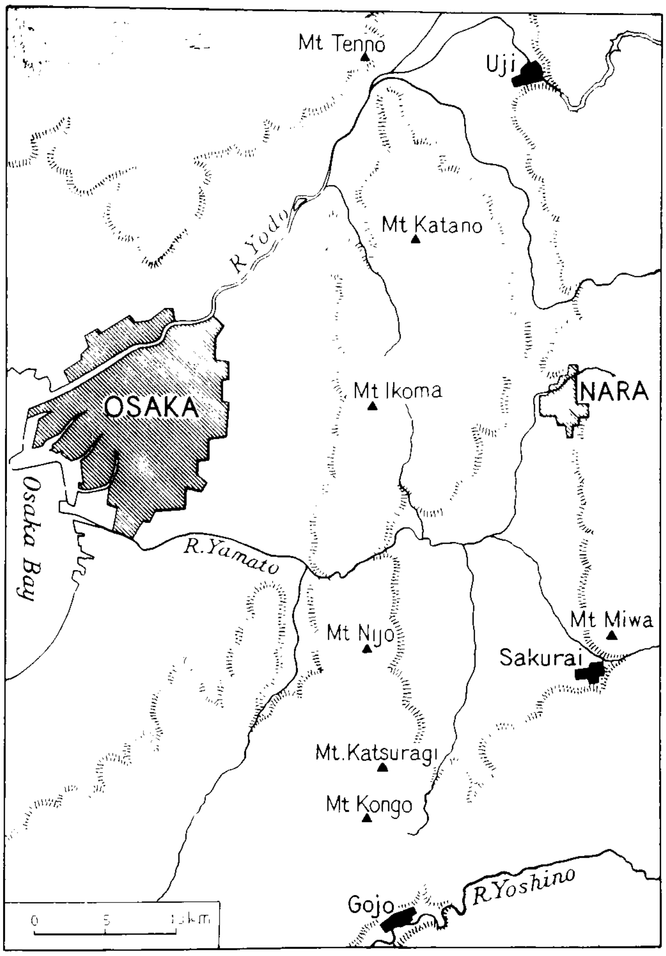


Fig. 1. Index map

* The geological map of the western part of the Ryoke metamorphic terrain in the Kinki district will be appear, together with the eastern and central district, in the following article:

H.Yoshizawa, W.Nakajima and K.Ishizaka

Geology of the Ryoke metamorphic belt in the Kinki district: accomplishment of a regional map of geology

General geology of the northern area

The area, between Mt.Kannabe and Mt.Ikoma, consists almost entirely of biotite granite, except for a small amount of quartz dioritic rock and hornfels.

1) Biotite granite

Biotite granite may be divided into the following three phases:

i. Coarse-grained biotite granite

ii. Medium-grained biotite granite

iii. Fine-grained biotite granite

Coarse-grained biotite granite occupies a small portion of this granite body. compared with medium-grained biotite granite. It is distributed in the southwestern part of Mt.Katano and in the southern part of Mt.Kannabe. This rock is coarse-grained, homogeneous and leucocratic biotite granite. It consists of large crystals of quartz, feldspar and biotite, each crystal being as large as 5~10mm in size. Occasionally, green hornblende is contained in some localities. As accessory mineral, allanite is found commonly.

This granite phase is quite similar to the coarse-grained biotite granite called "Ideminami granite" in the Kasagi district, which was described by Nakajima(1960). It may be the western extension of the "Ideminami granite" in the Kasagi district.

Medium-grained biotite granite is distributed most widely in this area, from the northern part of Mt.Ikoma to the southern part of Mt.Kannabe.

This rock is somewhat varied in its rock facies; changeable from coarse-grained facies to fine-grained facies. In several places, phenocrysts of potassium feldspar, sometimes as large as 1cm wide and 4cm long, develop.

In general, this granite is not foliated, but rarely found to be weakly foliated. Fine-grained granite is exposed only in limited area, i.e., in the south west of Mt.Katano. This rock is white-greyish, fine-grained granite, containing a small amount of muscovite. The mutual relation between them is that of transitional change. These granites may form a single granite body,i.e., co-magmatic and almost contemporaneous emplacement.

2) Quartz dioritic rock

Quartz dioritic rock develops in the medium-grained biotite granite in various sizes, usually small, and is considered to be in xenolithic relation to the biotite granite. This rock is generally dark-colored and fine-grained. The largest body occurs in the north of Tenno, reaching approximately to 1km x 1km wide. Around the marginal part of the quartz diorite, hornblende-biotite granodiorite develops and this gradually changes into medium-grained biotite granite. The biotite granite often becomes porphyritic around the quartz diorite body. Granitic veinlets are observed frequently to develop in net-work in the quartz diorite body. A small amount of dioritic to gabbroic rock exists in the core part of the large quartz diorite body , in the north of Tenno. The diorite is greyish and medium- to coarse-grained, the main constituents being plagioclase, hornblende, pyroxene and biotite. The gabbroic rock consists of basic plagioclase, monoclinic pyroxene, rhombic pyroxene and brown hornblende. The quartz dioritic rock, which is scattered in the biotite granite, may have been produced by the reaction between the pre-existing basic rocks and the granite magma. The gradual change, diorite → quartz diorite → granodiorite, may indicate this process.

5) Hornfels

A small Palaeozoic block, turned to hornfels by the contact metamorphism by the biotite granite, occurs at Mt.Kannabe. This hornfels body, assuming an ellipsoidal shape, consists of biotite hornfels, cordierite hornfels and a small amount of silicious rock of chert origin. The mineral assemblage of this hornfels is as follows:

Biotite hornfels	quartz-biotite-potassium feldspar- plagioclase Accessory minerals are muscovite, tourmaline, garnet and magnetite.
Cordierite hornfels	quartz-cordierite-biotite Accessory minerals are muscovite, tourmaline plagioclace and magnetite.

General geology of the southern area

The area, between Mt.Ikoma and Mt.Nijo, comprises metanorite, metamorphic rocks of sedimentary origin and several kinds of granitic rocks. A large amount of pyroclastic materials and volcanics of the Nijo group covers widely the area between Mt.Nijo and River Yamato.

1) Metanorite

Metanorite occurs in hornblende-biotite granite, constituting the top part of Mt.Ikoma, in approximately ellipsoidal shape. This is the largest metanorite body in the Ryoke metamorphic terrain in the Kinki district.

Although this metanorite seems to be a large body on the surface, it is assumed to become smaller in the sub-surface region and may be in xenolithic relation to the surrounding granite. This metanorite body was described in detail by Soma(1963). According to him, the metanorite may be divided into the following four facies:

1. Diabasic gabbro facies
2. Schistose amphibolite facies
3. Noritic hornblende gabbro facies
4. Dioritic gabbro facies

2) Metamorphic rocks of sedimentary origin

The metamorphic rocks of sedimentary origin in the southern area comprise mainly banded gneiss. The Mt.Matsuo mountain block consists mainly of the banded gneiss derived from psammitic sediments which is interbeded with a small amount of pelitic sediments. In the pelitic banded gneiss, the following mineral assemblage is observed;

sillimanite-cordierite-garnet-biotite-muscovite-potassium feldspar-plagioclase-quartz

This banded gneiss block is intruded by small bodies of hornblende-biotite granite or garnet-bearing fine-grained granite in several localities.

A small amount of silicious gneiss, probably derived from chert, occur in the northeast of Matsuo Temple.

3) Hornblende-biotite granite

Hornblende-biotite granite is mainly distributed in the southern part of Mt.Ikoma. This granite is generally coarse-grained and contains phenocrysts of potassium feldspar, being porphyritic. The amount of hornblende varies with exposures, usually being small. The rock facies varies considerably; for example, this granite turns into medium-grained biotite granite in the part directly south of the Ikoma metanorite body. This granite is in general foliated weakly, but shows conspicuous foliation at several exposures.

Judging from the similarity in the rock phase, this granite may correspond to the Yagyu granite in the eastern district.

4) Fine-grained granite

Fine-grained granite develops around Mt.Shigi. This granite is quite varied in its rock facies. It is mostly garnet-bearing two mica granite, foliated remarkably. Sometimes it resembles so much gneissose biotite granodiorite that it cannot be distinguished from the other megascopically.

In some localities, porphyroblasts of potassium feldspar, reaching to 2cm x 1cm in size, develop abundantly in this granite. There is no homogeneous biotite granite phase, as observed at Fukagawa in the eastern district.

5) Gneissose biotite granodiorite-gneissose hornblende-biotite granodiorite

These granitic rocks develop in the southern part of Mt.Shigi. These rocks are generally medium-grained, dark-colored and seems to be melanocratic. They are remarkably foliated and quite varied in their rock facies, like the fine-grained granite mentioned above. These rocks are mostly gneissose biotite granodiorite which contains only biotite as colored mineral, but hornblende-biotite granodiorite phase is observed in several localities, for example, near Takayasuyama. These granodiorites frequently contain small prolonged bodies of metamorphic rocks of sedimentary origin, usually banded gneiss, which extend concordantly with the foliation of the granodiorite. The gneissose granodiorite phase is quite similar in its appearance to the Koya granite which develops in the Kasagi district.

(ii) Mt.Katsuragi-Mt.Kongo area

In the northern part of this area, several kinds of granitic rocks, partly foliated, are distributed, in the middle part a large mass of non-foliated granodiorite occurs, which constitutes Mt.Katsuragi and in the southern part, sheared granodiorite and rocks of mylonitic character occur.

General geology of the northern area

Various kinds of granitic rocks, metamorphic rocks which are considered to have originated from pre-existing sedimentary rocks, basic metamorphic rocks and volcanic rocks are distributed in the region between the Takenouchi road and Mt.Katsuragi.

I Granitic rocks

1) Hornblende-biotite gneissose granodiorite
2) Biotite granite-Hornblende-biotite adamellite
3) Hornblende-biotite porphyritic adamellite

4) Pyroxene granite

5) Biotite-hornblende tonalitic gneissose granodiorite

II Basic metamorphic rocks

6) Metagabbro and other basic rocks

III Metamorphic rocks derived from sediments

7) Schistose hornfels

IV Volcanic rocks

8) Hornblende-pyroxene andesite

The north border of this area is covered by the pyroclastic materials of Mt.Nijo and the south limit of this area is bordered by the porphyritic biotite bearing hornblende granodiorite body. The east and west limits are covered respectively by the Alluvial deposits and the sedimentaries of the Osaka group.

I Granitic rocks

1) Hornblende-biotite gneissose granodiorite

This rock occupies the largest part of this area now under consideration and carries a fairly large amount of included bodies such as basic metamorphic rocks. Foliation develops considerably in this rock, although variable in its appearance. As a whole, this rock is not homogeneous in its rock facies. In this rock, the following facies which is somewhat different from the "hornblende-biotite gneissose granodiorite proper" in its appearance, occur:

i) The part in which extremely conspicuous foliation develops.

ii) The part in which foliation is so weak that it cannot be recognized by the naked eye.

iii) The part in which this rock becomes somewhat adamellitic.

All these facies are transitional with each other. The "hornblende-biotite gneissose granodiorite proper" is usually medium-grained, occasionally fine-grained and slightly melanocratic. In the amount of colored minerals, there is considerable difference. Especially the amount of horn-blende is variable. When this mineral appears in fairly large amount, [illegible] rock grades into gneissose tonalitic granodiorite. The rock phases i), ii) iii) mentioned above will be described below;

i) Remarkably foliated part is observed at the exposure in the southeast of Minamikano, in the east of Hiraishi and in the west of Kōki Temple. At these exposures, this rock is fine-grained and biotite crystal aggregates are in oriented arrangement, i.e., banded structure. Sometimes aggregates of porphyroblastic quartz crystals are elongated along the foliation in thin lens-shape.

ii) There is a non-foliated granodiorite phase in the gneissose granodiorite. This non-foliated part is transitional to a considerably foliated part. In general, this part is very similar to granodiorite in the usual sence in its appearance.

iii) The adamellitic part is occasionally observed in the gneissose granodiorite, the foliation of which is somewhat inconspicuous, being leucocratic. A fairly large amount of potassium feldspar. reaching to about 1~2cm in diameter, are observed. Around and/or in the phenocrysts, small biotite crystals develop. This adamellitic phase occupies only a small part of the gneissose granodiorite and is very similar to the hornblende-biotite adamellite, as will be mentioned later. No distinct boundary or intrusive relation is observed between the adamellitic phase and the gneissose granodiorite; they are in transitional relation.

2) Biotite granite~Hornblende-biotite adamellite

In general, biotite granite occupies the northern part of this rock body, and hornblende-biotite adamellite occupies the southern part. The former occupies only a small part, as compared ~~to~~ with the latter. These two rocks occur nearly in pararell to the porphyritic adamellite, extending N45°W between the metagabbro mass and the porphyritic adamellite mass.

i) Biotite granite

This granite is exposed typically along the cutting of the Takenouchi road, east of Ōmichi. This granite is nearly homogeneous, massive, medium- to coarse-grained and leucocratic, containing only biotite as colored mineral. A large quantity of alkali feldspar gives this granite a kind of grease luster, so that this rock looks very alkalic megascopically. At some exposures, this granite has fairly conspicuous foliation, with the direction of N10°W to N-S. Between this granite and porphyritic adamellite, there is observed a contact relation. At the part of contact between them, fine-grained, leucocratic granite develops. A distinct contact boundary is observed between the porphyritic adamellite and the fine-grained granite, while no such distinct boundary is seen between the biotite granite and the fine-grained granite.

ii) Hornblende-biotite adamellite

The hornblende-biotite adamellite is medium- to occasionally coarse-grained, granite-looking rock, which contains a fairly large amount of potassium feldspar. The amount of this mineral, however, varies with different exposures. Occasionally in this adamellite, phenocrysts of potassium feldspar approximately 1cm in diameter develop, but they are not so idiomorphic as in the case of porphyritic adamellite. Around and/or the phenocrysts, crystallization of very small biotite occurs. This adamellite resembles the biotite granite in its appearance. The following slight differences, however, between these rocks are recognizable:

1. This rock is more melanocratic than the biotite granite.
2. Hornblende is observed in the adamellite, together with biotite, although the amount of hornblende is small. On the other hand, the biotite graniteis lacking in hornblende.

These two rocks, i.e., the biotite granite and the hornblende-biotite adamellite are, the author considers, in different petrogenesis, as will be stated later.

3) Hornblende-biotite porphyritic adamellite

Large phenocrysts, nearly idiomorphic, of potassium feldspar reaching usually to 2~3cm in diameter, occasionally to 4~5cm, develop abundantly in this adamellite. The phenocrysts of potassium feldspar are distributed almost uniformly and abundantly throughout the rock body. The adamellite extends nearly N45°W, in approximately ellipsoidal shape. As for colored minerals, biotite is dominant. In some parts, where fairly large amounts of hornblende develop together with biotite, this rock seems to be melanocratic. The adamellite is considerably foliated, the foliation being conspicuous in the melanocratic part. Except for the abundant development of potassium feldspar phenocrysts, the matrix of the porphyritic adamellite is similar to the gneissose granodiorite.

4) Pyroxene granite

A small body of fine-grained pyroxene granite, which contains only ferrosalitic pyroxene as colored mineral is exposed in the porphyritic adamellite. on the cutting of Takenouchi road, east of Ōmichi. Unfortunately because of the lack of good exposures, the mode of occurrence of this rock could not be made clear. This granite is, the author considers, a replacement dike of the time of the metasomatism of the porphyritic adamellite.

5) Biotie-hornblende tonalitic gneissose granodiorite

This gneissose granodiorite is exposed typically in the east of Tōjō, in which the foliation with the direction of N50°W is developed. A fairly large amount of hornblend develops in it. With the decrease of hornblende this rock grades into gneissose granodiorite. Owing to the concentration of potassium feldspar. at the exposure northwest of Hiraishi, this rock lying closely to the porphyritic adamellite, becomes very alkalic.

Generally this tonalitic gneissose granodiorite occurs as a melanocratic member in the gneissose granodiorite or occasionally in the hornblende-biotite adamellite. It almost always occurs adjacent to the metagabbro mass or contains small xenolithic metagabbro masses. In some cases, it has been proved that this tonalitic rock originates from the metagabbroic rock, metasomatized by the granitic magma, as will be stated later.

II Basic metamorphic rocks

6) Metagabbro and other basic rock

A fairly large amount of metagabbro is distributed in this area. The metagabbro, medium- to coarse-grained and melanocratic, occurs usually as elongated xenolithic masses of various scales in the gneissose granodiorite or in the hornblende-biotite adamellite. It is varied in its rock facies and has various phases such as the following; relatively fine-grained phase, leucocratic phase which resembles the gneissose granodiorite and the melanocratic phase in which large crystals of hornblende, as large as 1cm long, develop. At the place where the metagabbro lies near the biotite granite or the hornblende-biotite adamellite, it becomes leucocratic,i.e., granitized metagabbro. Foliation develops in some parts of the granitized metagabbro. Small pegmatitic veins with random directions develop in the large masses of the metagabbro. The granitic veins are also observed in the metagabbro in the gneissose granodiorite. These granitic and pegmatitic veins are considered by the author to have been formed by the metasomatism of the granitic magma.

Besides the metagabbro, dark-green, fine-grained basic rocks of xenolithic lens or sometimes xenolithic dike, develop in the granitic rocks. The basic rocks usually form ~~the~~ aggregates of ~~the~~ xenolithic lens-shaped bodies.

III Metamorphic rocks derived from sediments

7) Schistose hornfels

In this region, metamorphic rocks of sedimentary origin develop only poorly. Small schistose hornfels bodies are found in the following two exposures; the cutting of the road between Kano and Mochio and the road cutting, south west of Hiraishi. At the former exposure, this rock occurs in the gneissose granodiorite, in dike-like xenolithes, about 50cm in width and extends parallel to the foliation of the country rock. At the latter exposure, it occurs also in the gneissose granodiorite, being of dike-like shape, about 7m in width. This schistose hornfels has the following mineral assemblage;

biotite-cordierite-quartz-plagioclase-potassium feldspar

Fairly large amount of cordierites, in porphyroblastic large crystals, are observed. They are partly replaced by chlorite. Feldspars comprise mainly plagioclase An_{32}, potassium feldspar being very small in its amount.

IV Volcanic rocks

8) Hornblende-hypersthene andesite

This andesite occurs in the south of Hiraishi, constituting a small hill of about 50m in height, on the gneissose granodiorite. In this rock, small blocks of granitic xenolith are recognized by the unassisted eye. This andesite is dark brownish, fine-grained and compact rock. Judging from the similarity of the mineral assemblage between this andesite and the rocks Mt.Nijo, these rocks may be co-magmatic. Two pyroxene andesite dike, about 2m in width, occurs in the gneissose granodiorite at the west of Hirokawa.

This dike rock is greyish and fine-grained. The andesite dike and the hornblende-hypersthene andesite may be of co-magmatic origin, judging from the texture and the mineral assemblage.

Microscopic character of hornblende-hypersthene andesite

Phenocrysts consist of hypersthene, plagioclase and hornblende.

hypersthene: idiomorphic long. columnar crystal or small square-granular crystal; a part of this mineral turns into iddingsite.

plagioclase: long tabular crystal; zonal structure is distinct; An_{55}

hornblende: round-elongated ellipsoidal crystal

X= yellow

Y= brownish yellow

Z= yellowish brown

occasionally coroded by groundmass

Xenocrysts consist of quartz, plagioclase and biotite. Fairly large amounts of xenocrysts are contained in this rock. Quartz and plagioclase is angular or is coroded.

quartz: occasionally large crystals are seen and include plagioclase; undulatory extinction is observed; reaction corona is occasionally observed around the round crystal of this mineral, this corona consists of aggregates of minute needle-like crystal, the optic character of which is $c \wedge z = 26^{\circ}$, positive elongation, this mineral is considered to be amphibole.

plagioclase: it takes angular forms of various size; zircon and apatite are included; reaction product with the magma is observed in this mineral, which is spinel(pale dark green) and tourmaline(yellowish brown~pale yellow, uniaxial, elongation negative)

biotite: long pole-like crystal; occasionally vermicular form is seen; it turns into iddingsite or gibbsite partly or completely; the amount of this mineral is not so large;

X= brownish yellow

Y≒Z= reddish brown

Groundmass sometimes shows flow texture and usually consists of minute needle-like plagioclase(An_{50}), augitic monoclinic pyroxene($C \wedge Z = 44^{\circ}$) rhombic pyroxene and glass. The augitic pyroxene is contained in extremely small amount.

General geology of the central area

The area, between the Mizukoshi road and the gneissose granodiorite mass comprises porphyritic biotite bearing hornblende granodiorite. It is characteristic of this rock that idiomorphic six-sided biotite crystals develop, reaching to 1cm in diameter and 1cm thick at the maximum. Together with the biotite phenocrysts, idiomorphic hornblende is contained as colored mineral. This rock is medium- to coarse-grained and seems to be leucocratic. It is massive and almost homogeneous at every exposure in its rock facies, though the amount of hornblende slightly varies with outcrops.

Except for the zone adjoining the gneissose granodiorite, basic rock xenolithes and dike rocks are extremely few in this rock body. At the place where this rock is adjacent to the biotite-hornblende granodiorite of the southern area, the biotite phenocrysts become inconspicuous and this granodiorite grades into the biotite-hornblende granodiorite in which idiomorphic biotite no longer develop. No intrusive relations are observed between them. Megascopically this granodiorite seems quite fresh, but the effects of probable deuteric alteration can be seen in thin section; biotite is partly turned into chlorite along its cleavage and is occasionally replaced by epidote. The epidote is probably deuteric mineral. It is clear from the fact stated above that this granodiorite body had undergone a deuteric alteration.

General geology of the southern area

The area, between the Mizukoshi road and the Izumi group comprises biotite-hornblende granodiorite, metagabbroic rock, garnet bearing aplitic granite, a small amount of metamorphic rock of sedimentary origin and various kinds of sheared rocks. Biotite-hornblende granodiorite mass is divided into two types; the one in which potassium feldspar is contained only as interstitial mineral, the other in which blastporphyritic potassium feldspar is contained in various amounts. The rocks in the southern part of the line connecting the top of Mt.Kongo, Chihaya and Nishibata, are sheared to various degrees. Although a small amount of sheared rocks occurs in the northern side of this line, the granodiorite in this part is generally not sheared, as compared with that in the southern side. Sheared zones of various scales, extending nearly E-W, are distributed in the southern part of the granodiorite mass. Several small dikes of quartz porphyry occur in the sheared granodiorite and are also sheared. Foliated metagabbroic rocks occur in the south of Nishibata in the granodiorite. Mylonitic rocks occur in the southern part of the granodiorite mass, extending E-W or N-S.

In several places, between Chihaya Pass and Amami, sheared aplitic granite develops, extending nearly E-W. Garnet bearing aplitic granite crops out near Azumasaka in the non-sheared biotite-hornblende granodiorite. Metamorphic rocks of sedimentary origin occur as small dike-like xenolithes in the biotite-hornblende granodiorite, north of Mt.Hataodake. Many faults, with the direction mainly N-S or E-W, develop in the sheared granodiorite.

At the south limit of the granodiorite mass, sheared granodiorite contacts with the Izumi group. Generally speaking, the relation between them is fault and unconformity.

1) Non-sheared biotite-hornblende granodiorite

This granodiorite is typically exposed along the road cutting, north of Chihaya. It is a light-greyish and medium-grained rock in which a considerably large amount of hornblende, reaching to 1cm long at the maximum, develops. This granodiorite contains a fairly large amount of basic xenolithes and occasionally metagabbro masses. The minimum size of the basic xenolith is a few centimeters, but large masses 100m wide and 1km long occur rarely. The basic rock xenolithes included in this granodiorite are not lens-shaped and are not arranged in orientation, as those of the gneissose granodiorite in the northern part.

2) Garnet bearing aplitic granite

This granite is generally leucocratic, fine- to slightly medium-grained. The relation between this rock and biotite-hornblende granodiorite is not clear, because of the lack of good exposure. But judging from the fact that this aplitic granite occurs in stock-like shape in small scale in the granodiorite, it may have intruded in the later stage of the igneous intrusion.

3) Metagabbroic rock

A large xenolithic mass of metagabbroic rock occurs in the south of Nishibata. This rock is generally melanocratic but in the granitized part becomes leucocratic. Schistosity develops remarkably throughout this rock body. Under the microscope, cataclastic texture is found to be remarkable in this rock, especially in the strongly granitized part.

4) Sheared rocks

i. Sheared biotite-hornblende granodiorite

This rock is sheared to various degrees. In the case where it is not so intensively sheared, it is quite similar to the non-sheared biotite-hornblende granodiorite. This sheared granodiorite assumes dark green to dark grey color. due to chloritization and silicification. In some places, this rock assumes reddish brown color due to intensive hydrothermal alteration.

The development of such hydrothermal minerals in veinlet as calcite, epidote, zoisite indicates that hydrothermal alteration worked intensively on this sheared granodiorite. Occasionally large pink alkali feldspars(microcline perthite), as large as 1cm x 2cm , occur in the sheared granodiorite.

These large alkali feldspars are considered to be blastporphyrytic, as will be mentioned later. The scale of the sheared part is variable; sometimes the sheared parts are observed to grade into joints or fissures of the granodiorite. Several narrow sheared bands gather into a large shear zone.

Such sheared zones of various scales are observed in many parts of the sheared granodiorite.

ii. Description of the sheared granodiorite

Cataclastic textures of various degrees are observed in the sheared granodiorite under the microscope. Gradation in texture from granitic to mylonitic can be traceable:

1) Some of the sheared granodiorite is not so greatly different from the non-sheared granodiorite in texture. Microscopic character is as follows;

Quartz: xenomorphic crystal, undulatory extinction is faint.

Plagioclase: hypidiomorphic, long prismatic or tabular crystal; bending in crystal is observed; oscillatory zoning is developed; An_{44}

Biotite: hypidiomorphic, tabular crystal: occasionally it is decomposed to small flake aggregates and is chloritized.

X= straw yellow

Y≒Z= reddish-dark brown

Hornblende: hypidiomorphic crystal: partly it is replaced by biotite: intergrowth with biotite is observed.

Potassium feldspar: this mineral is present only as interstitial mineral.

2) In mylonite, the minerals composing the rock are similar to those composing granodiorite. but cataclastic texture develops far more remarkably than in any other sheared rock in this area. In this rock, quartz and plagioclase are completely crushed to almost equigranular and fine grains.

Biotite and hornblende are decomposed to small grains or flakes and turned partly into chlorite. These minerals are arranged in orientation and shows remarkable schistosity.

3) As intermediates between the two stated above, there are sheared rocks which show various types of cataclastic textures. In these rocks, quartz forms aggregates of irregular grains with sutured texture or is sometimes crushed to angular pieces. Plagioclase is also crushed to angular or granular pieces. In relatively large plagioclase crystals, bending, breaking down and torsion are observed. Vein-like masses of these small grains, aggregates penetrate into plagioclase crystal. Aggregates of minute grains of plagioclase develop around the large crystals of plagioclase, and the large crystals become blastoporphyritic.

Biotite crystals show only bending and torsion when cataclastic texture is not conspicuous, but usually they are decomposed to aggregates of small flakes. These aggregates are generally elongated in orientation.

Hornblende behaves similarly as biotite. The sheared granodiorite is also hydrothermally altered in many cases. Colored minerals such as hornblend and biotite are partly or completely changed into hydrothermal minerals such as chlorite, epidote and zoisite etc.

Plagioclase is kaolinized or occasionally turned into epidote or calcite.

In the sheared granodiorite, potassium feldspar occurs in various amounts. Potassium feldspar shows gitter texture and perthite texture, being microcline perthite. This mineral is contained only interstitially in the non-sheared granodiorite which occupies the northern part of the granodiorite mass, while it is contained fairly abundantly in this sheared granodiorite of the southern part. In some places, as stated previously large microcline crystals occur in the sheared granodiorite.

Vein-like aggregates, consisting of minute quartz and plagioclase grains, penetrate the large microcline crystals, and also fine-grained aggregates of mainly plagioclase and microcline develop around the microcline crystals.

Furthermore it has been observed that in mylonitized granodiorite which is extremely schistose, such minerals as quartz and plagioclase are granulized or crushed, large crystals of microcline are surrounded by fine-grained aggregates of these minerals, and sometimes these large microcline crystals are penetrated by these fine-grained aggregates.

From these observations, it is obvious that the large crystals have gone through the shearing as well as the other minerals. Thus the large microcline crystals in the sheared granodiorite are not porphyroblastic, but blastporphyritic; this microcline is the relic of the porphyroblast which had existed in this rock before the shearing operated. In this respect, the large microcline crystals in the sheared granodiorite are quite different from those in the porphyritic adamellite of the northern part, which were produced by alkali metasomatism and were not sheared.

iii. Sheared aplitic granite

Sheared aplitic granite, free from colored minerals, occurs in the sheared granodiorite in various scales. This rock occurs as a fairly large mass in the strongly chloritized and silicified sheared granodiorite near Chihaya Pass. This aplitic granite is generally fine-grained, very leucocratic and compact. Besides above mentioned exposures, this rock is also observed on the following places; Ishimigawa, Jūji Pass and Amami. As a whole these exposures are distributed extending nearly E-W, which direction coincides with the general trend of the sheared zone. At Amami, this aplitic granite injects as a dike-shaped body into the basic rock or the porphyrite in the sheared granodiorite.

According to the observation under the microscope, this aplitic rock, occurring near Chihaya Pass, is completely crushed to small granular pieces. This rock should therefore be called "microbreccia".

On the other hand, the texture of the rock which is exposed as dike-shaped body at Amami is quite similar to that of aplitic granite in the usual sence. From these field and microscopical observations, it is considered that the aplitic granite once existed in this area before the operation of the shearings, as a continuous dike of a fairly large scale, extending nearly E-W. With the action of the shearings, this aplitic granite may have been crushed in various degrees.

iv. Mylonitic rocks

Two kinds of mylonitic rocks are observed in the sheared granodiorite. The one is a fine-grained, dark grey or almost black and compact rock with remarkable schistosity. and the other is medium-grained and somewhat granodioritic, in which schistosity develop considerably.

The former, a few meters thick, is observed at Akadaki and Myokendani, extending nearly E-W. The latter, also a few meters thick, is exposed near Shimauchi and other places, extending nearly N-S or N-E.

Judging from the microscopic observations, these mylonitic rocks may have been produced from the biotite-hornblende granodiorite occupying this area.

v. Sheared basic rock

On the cutting along the road near Nishinotani, sheared rock which is considered to have been derived from basic rocks crops out in the sheared granodiorite. It is dark colored, almost black and is completely crushed. This sheared basic rock consists of very fine grains of quartz, plagioclase and hornblende. It may be porphyrite or basic rock of xenolithic origin.

5) Summary concerning the sheared area

In this area, sheared zones of various scales, consisting of sheared granodiorite, are distributed in the non-sheared granodiorite. The extending direction of the sheared zone is generally E-W. It is considered that the sheared rock was formed in a shallower horizon than that in which the foliation of the granodiorite was formed. The dislocation metamorphism by which the sheared rock was formed, might have begun before the deposition of the Izumi group, because a part of this sheared rock is found in the pebbles of the basal conglomerate of the Izumi group. The mylonitic rocks, which were formed by maximum displacing movement in this metamorphism, are found in the sheared rocks, extending E-W. N-S or N-E.

The stage, when the foliation was formed in the gneissose granodiorite and in other rocks, is earlier than that of dislocation metamorphism; namely, the foliation of the granodiorite and other rocks, was formed in deeper zone than that in which the sheared rock was formed.

Many small faults, generally a few centimeters wide, are observed in the sheared zone. These carry fault clay and considered to be later in stage than the formation of the mylonite. Furthermore, a considerably large fault lies near Yamada, northwest of Gojō. A large block of the Izumi group is moved northward by this fault. This fault is also one of the faults of the later stage. The age of the formation of the mylonite may be pre-Izumi to post-Izumi.

The blastporphyritic large crystals of microcline, as stated previously, occur in the sheared granodiorite. Therefore, the author considers as follows. The porphyroblast had existed in the granodiorite before this rock was sheared. The porphyroblast had been formed in a part of the granodiorite in this southern area in which various amounts of microcline occur. During the time when granodiorite was rising up from the deeper zone by upward folding, the porphyroblast was formed by the operation of some agents before the granodiorite had reached the shallow zone, and went through the dislocation metamorphism. As for the relation between the formation stage of the porphyroblast in the granodiorite and that of the porphyritic adamellite of the northern part, it is not determined whether these stages may be the same or not, because the two areas are isolated and consist of different rocks. The fact that the amount of blastporphyritie relics of microcline is variable in the granodiorite can be explained by the fact that this rock was not affected uniformly by the shearings.

(iii) The mutual relations among the granitic rocks in the Kongo-Katsuragi area

The basic rocks represented by gabbro and diabase may have been once distributed widely in this area before the intrusion of granitic magma, judging from the fact that metamorphic rocks of sedimentary origin are poorly developed, whereas metamorphosed basic rocks are distributed abundantly in the granitic rocks. Judging from the field observations, the granitic rocks are possibly intrusive body and metasomatized rocks due to granitic magma, but not the product of granitization in solid state.

From the fact that the gneissose granodiorite is distributed most widely in this area, this magma is considered to be granodioritic. Also, from the fact that the foliated biotite granite occurs in this area, the granite magma is considered to have originated partly from the granodioritic magma. Possibly this granite magma was produced from the granodiorite magma by differentiation. By the metamorphism, i.e., the Ryoke metamorphism, which is accompanied by the intrusion of the granitic rocks in this area, foliation was formed in the gneissose granodiorite and in the granite. By this metamorphism, metagabbro and metadiabase were formed from gabbro and diabase. The gneissose tonalitic granodiorite which is seen in the gneissose granodiorite and in the hornblende-biotite adamellite was also formed from gabbro by the metasomatism of the granodiorite or the granite magma, which is shown in the fact that cummingtonitic amphibole is observed as relict mineral in green hornblende and occasionally a large amount of iron mineral (illmenite) is scattered all over.

Porphyritic adamellite was formed by metasomatism of alkali-alumina emanation in a later stage, which is quite different from metamorphic stage. A part of hornblende-biotite adamellite was also formed by the same metasomatism. The fact that in some places adamellitic part occurs in the gneissose granodiorite may be explained by the metasomatism of the later stage; this part may correspond to metasomatized granodiorite.

The relation between these granitic rocks and porphyritic biotite bearing hornblende granodiorite is , the author considers, transitional.

The reason is as follows; the gneissose granodiorite has moderate foliation with the direction of N60°E, along the road cutting , north of Hirokawa. But as one approaches from the granitic region to the porphyritic biotite bearing hornblende granodiorite, one finds that the foliation in the gneissose granodiorite becomes inconspicuous and finally turns into non-foliated granodiorite. At the same time idiomorphic six-sided biotite crystals begin to appear and increase in amount. No intrusive relation is observed between these two rocks. Judging from the fact that this granodiorite has no foliation, the granodiorite is considered to have been in a completely liquid state throughout the metamorphism.

III. A consideration of the genesis of the microcline phenocrysts in the porphyritic hornblende-biotite adamellite

It has been a well-known fact that microclines occur as large idiomorphic phenocrysts in granitic rocks. Many explanations have been proposed, according to which, the microcline phenocrysts are considered to have been formed by a later metasomatic action, for example, by the action of alkali-alumina emanation of granitic magma in deuteric stage. In this paragragh, the author will deal with the genesis of the microcline phenocrysts in the porphyritic adamellite from both field and microscopical observations.

1. Field observations

a) The porphyritic adamellite has foliation, when the rock becomes melanocratic, as stated previously. In this part, the microcline phenocrysts develop by crossing the foliation. Around the phenocrysts, biotite band is curved as if the minerals were pushed aside by the development of the crystallizing microcline phenocrysts.

b) In the parts adjacent to the porphyritic adamellite, remarkable concentration of alkali occurs as follows;

i) In the east of Ōmichi, fine-grained, leucocratic granite occurs near biotite granite. This fine-grained granite contacts with the porphyritic adamellite. The contact boundary between these two rocks is distinct , while the fine-grained granite grades into the biotite granite.

ii) In the east of Higashijo, fine-grained, leucocratic granite occurs in a small scale in the hornblende-biotite adamellite, which adjoins the porphyritic adamellite. In this hornblende-biotite adamellite. adjacent to the fine-grained leucocratic granite, microcline phenocrysts, approximately 1cm in diameter, occur occasionally. But these phenocrysts are not idiomorphic and extremely few in number, as compared with ~~to~~ those of the porphyritic adamellite. In the microcline phenocrysts small crystals of biotite are included.

c) In the north of Hiraishi Pass, where the porphyritic adamellite and the gneissose tonalitic granodiorite occur closely together, the following facts are observed; fine-grained, leucocratic granite occurs. adjacent to the porphyrytic adamellite. The contact between them is distinct, as that in the case of (b). In the gneissose tonalitic granodiorite, adjacent to the fine-grained granite, a remarkable concentration of microcline is observed. Though this gneissose tonalitic granodiorite is melanocratic, microcline concentrate so intensively that this rock looks quite alkalic (microcline is colored pale pink). Sometimes in this part, phenocryst-like aggregates of small microcline crystals, about 2cm in diameter, are observed.

d) At the exposure in the east of Hiraishi Pass, similar concentration of alkali occurs in the hornblende-biotite gneissose granodiorite. adjoining the porphyritic adamellite. Aggregates or veinlets (2~3cm wide) of microcline crystals are observed to develop in this gneissose granodiorite.

The veinlets, consisting of microcline aggregates, may be called pegmatite of small scale. Furthermore, the gneissose granodiorite is injected by the fine-grained granite.

2. Microscopic observation

a) Microcline phenocrysts develop, replacing other minerals and include them poikilitically.

b) Large porphyroblastic quartz crystals, accompanied by microcline phenocrysts, are observed. They also include such minerals as plagioclase and biotite poikilitically. These large crystals of quartz show almost no undulatory extinction, when compared with ~~to~~ the small xenomorphic crystals, which are considered to have been crystallized directly from magma in earlier stage.

c) Around the microcline phenocrysts, aggregates consisting of small biotite flakes develop. These biotite are considered to be the product of recrystallization.

d) There are some parts, in which aggregates of small granular crystals, composed of quartz and plagioclase, develop. These aggregates, showing mortar texture, are also considered to be the product of recrystallization.

e) Carlsbad twins of phenocrystic microcline develop by traversing such minerals as biotite and plagioclase, which are included in it.
f) When plagioclase contacts with microcline phenocrysts, myrmekite and thin albitic rim always occur remarkably.

From these observations both of the field and of the laboratory, the author considers as follows. Microcline phenocrysts in the porphyritic adamellite are formed metasomatically, judging from the microscopic observations stated above, for instande, from the microscopic observation (b).

It is considered that there were two stages in the time of the crystallization of quartz; porphyroblastic quartz may have been formed in the later stage metasomatically. for the porphyroblastic quartz does not show undulatory extinction. Microcline phenocrysts develop by crossing foliation.

This fact indicates that alkali metasomatism had taken place in a slightly later stage than the metamorphic stage in which the foliation of the granitic rocks and undulatory extinction in the quartz crystals were formed.

Potassium needed for replacement may have been derived from the magma from which the biotite granite and fine-grained leucocratic granite were formed. The granite in the metamorphic stage is represented by the foliated biotite granite. But from the fact that fine-grained leucocratic granite injects into the gneissose granodiorite in several places, it is considered that the granite magma remained in some part of the gneissose granodiorite and was active until the later stage.

The granites which are observed in the gneissose granodiorite and around the porphyritic adamellite, are fine-grained and leucocratic. From this fact, it is assumed that the granite magma contained silica and alkali abundantly; this magma may be the residual magma of the deuteric stage.

In some parts adjoining the porphyritic adamellite, aggregates of microcline crystals, develop and concentration of microcline occurs even in the gneissose tonalitic granodiorite, in which usually only a small amount of potassium feldspar exists. From these facts, it is known how large a quantity of potassium was introduced into the porphyritic adamellite and the adjoining parts. Thus microcline phenocrysts in the porphyritic adamellite are formed metasomatically by the action of alkali-alumina emanation from the residual magma.

IV. Summary of the geology on the western part of the Ryoke metamorphic terrain in the Kinki district

As stated previously, the western part of the Ryoke metamorphic terrain in the Kinki district, consists almost entirely of granitic rocks. Except for one banded gneiss block, constituting Mt.Matsuo, the metamorphic rocks of sedimentary origin occur only as small dike-like xenolithes in granitic rocks in several localities. Because of abundant granitic intrusions, the geological structure in this region is obscured to a greater degree.

Furthermore, this region consists of a mountain range, which is isolated from that in the eastern district. Consequently, the geological relation to the eastern district is somewhat obscured. From the information obtained through this study, the geology in this region can be summarized as follows.

1. The biotite granite, distributed widely in the northern region of Mt.Ikoma, may be correlated to the so-called "Cretaceous granite", judging from the lithological similarity and geological situation. No boundary is observed between these two granites. They are transitional in their petrographical properties. The hornblende-biotite granite corresponds to the Yagyu granite of the eastern district, judging from the similarity in the rock facies.

2. The gneissose granodiorite, developing in the central part of the studied region, is separated into two blocks by the pyrocrastic materials and the volcanics of the Nijo group covering the gneissose granodiorite: The one develops in the north of River Yamato (northern block), and the other develops in the south of Mt.Nijo (southern block). A considerably sharp contrast exists between these two blocks.

   a) In the northern block, a considerable amount of metamorphic rocks of sedimentary origin occur as inclusions in the gneissose granodiorite, whereas in the southern block, they are extremely rare.

   b) In the southern block, a large amount of basic metamorphic rock develops, but in the northern block, they are few.

It is considered from the above-stated fact that there had been considerable difference in the original geological setting between these two regions; in the northern block, Palaeozoic sedimentary rocks, with only a small amount of basic igneous rocks, developed widely. In the southern block, on the other hand, there had been intensive intrusions of the basic igneous rocks such as gabbro and diabase in the Palaeozoic strata.

3. The geological structure of the studied area, indicated by gneissose granodiorite and fine-grained granite, is monoclinal, having northward dipping. No anticline or syncline which develops well in the eastern district of the terrain is observed in the studied area.

4. In the northern part of Mt.Kongo, biotite porphyritic hornblende granodiorite occurs. This granodiorite (Katsuragi granodiorite) is very characteristic, as mentioned below, differing from any other granodiorite body in this region.

a) This granodiorite is free from any inclusion except for the marginal part adjoining gneissose granodiorite.
b) It contains idiomorphic six-sided biotite and long prismatic hornblende crystals.
c) It is coarse-grained and not foliated.

In the eastern district, i.e., in Mie Prefecture, non-foliated granodiorite body similar to this rock occurs in gneissose granodiorite region.
This non-foliated granodiorite is considered to represent the core part in the metamorphic terrain. Consequently the Katsuragi granodiorite may be correlated to this granodiorite in the eastern district and represent the core part of the western part of the Ryoke metamorphic terrain in the Kinki district, judging from their petrology and geology.

5. A hornblende-hypersthene andesite, having many granitic xenolithes was found by the author in the time of his survey. This andesite forming a small cone, is situated approximately 5km south of Mt.Nijo, which undoubtly belongs to the Setouchi volcanic group.

Part II A Geochronological study of the Ryoke metamorphic terrain in the Kinki district

I Experimental procedure

General statement

In this investigation, all determinations of the concentration of rubidium, strontium and some of potassium were made by isotope dilution method (Webster 1960).

The method involves following procedures; a known amount of "spike" is added to a known weight of a sample. The "spike" is a solution of the element to be analyzed whose isotopic composition has been greatly enriched by one or two of the isotopes of this element.

After reaching equilibrium, the element to be analyzed is separated from other elements by chemical procedures. The isotopic ratio measurement is made on a mass spectrometer on the separated element which is a mixture of the "spike" and the element having normal isotopic composition. Knowing the amount and the isotopic composition of the "spike". the amount of the element to be analvzed in the sample is calculated.

The determination of the concentration of argon was also made by isotope dilution method of analysis. In this case, a known amount of gaseous "spike" is added to released gas from a known weight of a sample.

Instead of chemical procedure, gas purification tecnique was used.

1. Sample preparation

All sample specimens were collected so as to provide freshest material as possible. Most of rock specimens were collected at fresh road cuttings and quarries. The mineral samples analyzed in this study were mostly biotite. A few muscovite. potassium feldspar and hornblende were also analyzed. The mineral samples as possible as pure were prepared.

Because in the Rb-Sr method, contamination of mica with chlorite or hornblende adds normal strontium which reduces the accuracy of the results.

Generally the rock specimen was crushed in a steel mortar to less than 65 mesh, usually −65 +100 mesh. This fraction was passed through a isodynamic separator several times, until clean separates were obtained.

The contaminating hornblende or feldspar in the biotite separate was eliminated by tilting and gently tapping the filtered paper on which the biotite fraction was poured out. This procedure was repeated several times.

By these treatments, usually clean biotite samples free from hornblende or feldspar were obtained.

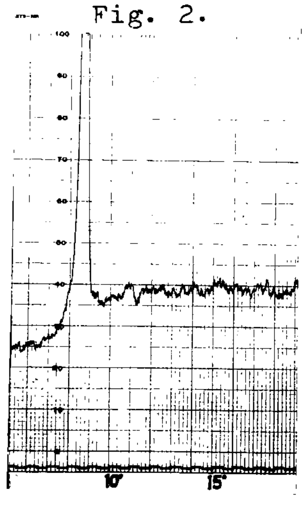
But chlorite was not eliminated by these procedures. All biotite samples were observed under a binocular microscope to detect chlorite.

If chlorite flakes were found in the biotite sample, this was grounded to less than 150 mesh. The fine flakes were centrifuged in a heavy liquid (methylene iodide and aceton mixture) to float off chlorite.

The final separate was monitored by a Norelco X-ray diffractmeter: After grounded to a fine powder, it was mounted on the Norelco and a diffraction pattern was taken between $2\theta = 5^{\circ}$ and $2\theta = 15^{\circ}$. The typical spectrum which shows no chlorite peak $2\theta = 12^{\circ}-13^{\circ}$ is presented in Fig. 2.

Muscovite was crudely separated from the non-magnetic fraction by passing it through the isodynamic separator. The contaminants such as feldspar and quartz, were eliminated by floating them in bromoform and by tapping on a filter paper

Fig. 2.



X-ray powder chart of biotite separate

Alkali feldspar, usually microcline, was separated from the non-magnetic fraction (Q+Pl+Kf) in a bromoform and aceton mixture. The floated alkali feldspar was grounded to less than 200 mesh and washed by water to float off fine dust. Potassium feldspar was separated from the fine powder by centrifuging in the bromoform and aceton mixture which was adjusted to float albite.

Three hornblende samples were prepared for the K-Ar analyses. Hornblende was firstly separated from the magnetic fraction (Bi+Ho) by passing it through the isodynamic separator. The hornblende fraction was poured onto the filter paper which was tilted and tapped to eliminate biotite.

Methylene iodide and aceton mixture was used to float contaminating biotite. This procedure was repeated until optimum result was obtained.

Then hornblende was crushed to less than 200 mesh and decanted. It was again dealt with the methylene iodide -aceton mixture. Finally hornblende obtained through these procedures was observed under a binocular microscope.

Each hornblende sample was 95 percent pure or more, judging from grain counting under the microscope.

In case of a book mica of pegmatite, it was cut by a scissor into fine flakes,and no further treatment was made. All mineral separates which were separated in a heavy liquid were washed repeatedly by aceton, alcohol and finaly by deionized water and were dried at 110° C.

For preparation total rock samples, fresh fist-sized pieces of rock specimens were crushed in a clean steel mortar to pass 100 mesh screen and thoroughly mixed. In case of coarse-grained or heterogeneous rock sample, about 500-1000 grams of the rock was crushed.

2. Determination of rubidium and strontium

i. Reagents and Apparatus

As the isotope dilution method such as used in this study deals with μg or subμg quantity, extreme cares should be exercised to avoid any contamination through chemical reagents and apparatus.

The water was deionized through a commercial mono-bed type ion exchange column, which was further purified by redistilling in a quartz still.

The A.R. grade hydrochloric acid was redistilled as constant boiling acid in the quartz still. Both water and hydrochloric acid were stored in polyethylene bottles. The A.R. grade hydrofluoric acid was redistilled in a still made of Teflon placed in a electric furnace regulated by a convenient slidac. The A.R. grade perchloric acid and sulphuric acid were used without further treatment.

Glass wares used in this study were all made of quartz or Pyrex glass.

Teflon beakers, covers, stirring rods and all glass wares were cleaned in hot hydrrochloric acid at least overnight prior to use.

The ion exchange columns have no stop cocks and were cleaned by washing with quartz-distilled HCl repeatedly. After the cleaning, the resin was slowly settled in a Pyrex tube, nearly 20 cm length and 1 cm in diameter.

ii. Chemical Procedure

The chemical procedure used in this study is essentially identical with that described by Aldrich et al. (1956).

The procedure was made simple as possible, because complicated treatment might introduce contamination. To speed up the analyses, six samples were treated at one time. For this purpose, six Teflon beakers and six Pyrex made ion exchange columns were prepared. The columns had been already traced for Sr and Cs (instead of Rb) using radioactive tracer technique, so that approximate places for these two elements were known. #1

As a result no Sr radioactive tracer was added to each sample in this study.

A typical chemical procedure was carried out in the following manner:

1. Mineral sample (approximately 300 mg for biotite, 200 mg for muscovite and 100 mg for potassium feldspar) was weighed out into a clean Teflon beaker.

2. A known amount of Sr^{86-84} spike solution was added to the sample from a calibrated pipette. (pipette #1 0.7700 ml)

3. 5~20 ml HF and then 5 ml $HClO_4$ were added. With a cover on the beaker, the sample was heated on a hot plate in a fume hood and decomposed. When the mineral flakes went all into solution, the cover was taken. Until $HClO_4$ fume nearly ceased being evolved, heating was continued.

4. The residue was then dissolved in quartz-distilled water and diluted to about 80 ml in the Teflon beaker. The water solution may be stirred by a clean Teflon stirring rod to dissolve any residue present.

If the residue is not dissolved easily, 2.5N or 6.2N quartz-distilled HCl may be used, instead of water.

5. If the residue went all into solution, this solution was left for one or two days to assist the mixing of the Sr spike and Sr in the sample to be complete. In this step cares must be exercised to be sure that the solution is completely homogenized.

6. A 1~3ml fraction, the weight of which was measured gravimetrically, was poured into the 10 ml quartz beaker which contained appropriate amount of $Rb^{87}-K^{41}$ spike solution.*2 This solution was diluted to 8~10 ml and homogenized by adding quartz-distilled water. 1~2 drops of H_2SO_4 were added and evaporated to dryness to convert to sulphate. This was set aside for rubidium analysis.*3

7. The original solution was evaporated to dryness. About 2 ml of 2.5N quartz-distilled HCl was added to the dried perchlorate. The content was poured into a 2 ml Pyrex made centrifuge tube and centrifuged.
Precipitates consisting largely of KCl, BaCl etc. were deposited in the bottom. Most of strontium was left in the solution.

8. The strontium was separated from other elements by cation exchange techniques using Dowex-50, 200-400 mesh, 12% cross linked ion exchange resin and 2.5N quartz-distilled HCl as eluant. The ion exchange columns were cleaned between successive runs by washing with 80-100 ml 6.2N quartz-distilled HCl and then with 2.5N HCl. The top of the resin was then leveled and approximately 1 ml of the sample solution was placed on the column by means of a pipette. After the solution was absorbed on the resin, it was eluted with 65 ml of 2.5N HCl. The column was then eluted with an additional 25 ml of 2.5N HCl. The 25 ml fraction containing most of strontium was collected in a 30 ml Pyrex beaker. Several drops of $HClO_4$ were added to this aliquot to destroy any resin present. The content was then evaporated to dryness. This was stored until it could be analyzed on the mass spectrometer.

In preparation for the isotope analysis, the strontium perchlorate in the 30 ml beaker was dissolved in a few drops of quartz-distilled water.
This solution was deposited in the center of the outgassed tantalum filament in the source by means of a medical syringe using a clean Pyrex capillary tip. The filament temperature was raised for an instance, until that at which the fume evolve to expell occluded gas from the sample, to convert the perchlorate to oxide. The source was reassembled and placed in the tube of the mass spectrometer.

*1) The position of the Sr and Rb of the eluant were traced on each column (column 1~column 6) by adding and counting radioactive tracers. Sr^{89} and Cs^{137} were used as the radioactive tracers in this experiment.

Cs^{137} was used instead of Rb^{86} which was difficult to obtain. Caesium is known to be eluted after rubidium.(3)

The sample, approximately 300 mg of biotite, was weighed into a Teflon beaker. Approximately 1μC of Sr^{89} and Cs^{137} was added to the weighed sample. This sample was received exactly identical treatment described above (3)-(8). About 1 ml of the sample solution in the centrifuge tube was placed on the column and it was eluted with 100 ml 2.5N quartz-distilled HCl.

The eluant was continuously collected in approximately seventy test tubes mounted on a fraction collector. Each test tube contained about 1.4 ml of the fraction. Iron was traced visually by its yellow color. Cs^{137} was traced by counting its γ activity in a γ-scintillation counter. After the counting the γ activity of Cs^{137}, the contents in all test tubes were transferred to stainless steel dishes and dried in a hood. The dried content in the dishes was counted its β activity in a β-scintillation counter to detect the portion of Sr^{89} Of all ion exchange columns used in the present study, it was assured that most of Sr was contained in the 65-90 ml fraction and that Sr was separated from Rb nearly perfectly, as is shown in Fig. 3.

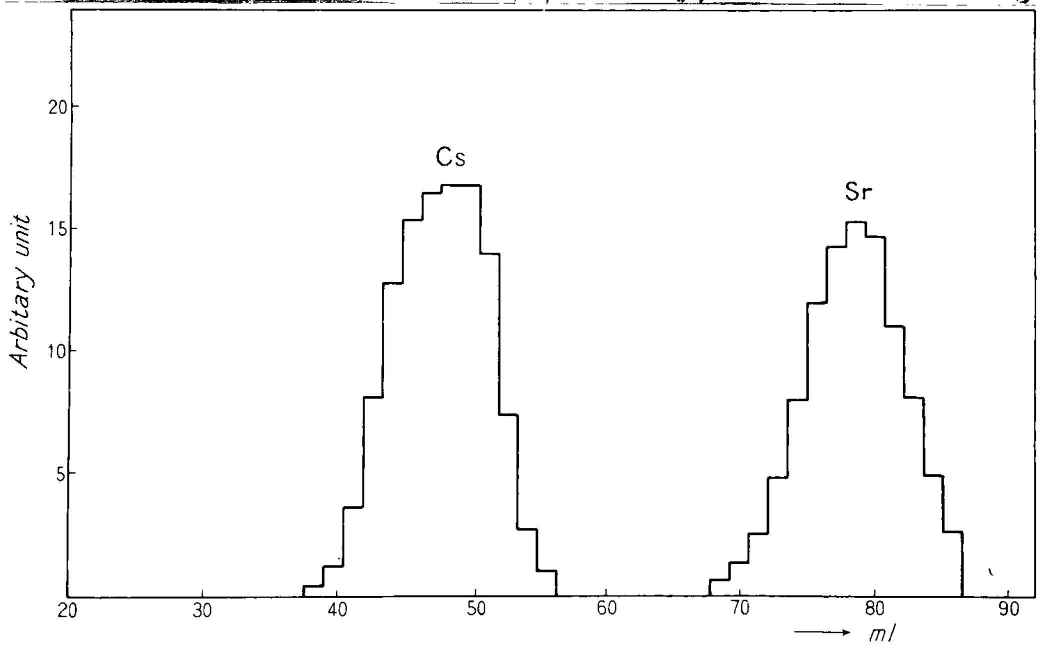


Fig. 3. Separati[illegible] [illegible] Sr from 300mg sample of biotite

*2) Appropriate amount of Rb^{87}- K^{41} spike solution was delivered from the stock solution in a 100 ml Pyrex flask to approximately fifty 10 ml quartz beakers, which were numbered, covered with Parafilm and stored untill it was used. Delivery was made by means of a calibrated pipette #4 (1.1219 ml).

The amount of the delivered spike solution was also measured gravimetrically. The gravimetric value was preferred for the calculation.

*3) No attempt was made to separate Rb from other elements or to purify Rb. The sulphate in the 10 ml quartz beaker was moisted by a few drops of quartz-distilled water, directly placed on a filament in the ion source for the isotope analysis. To evaluate this procedure, normal Rb^{87}/Rb^{85} ratio was measured on two biotite. The sulphate samples were prepared under the identical procedure described previously, except that they were not spiked with Rb^{87}. The results were as follows:

Specimen No.	Rb^{87}/Rb^{85}	Mineral	Rock
R-4005	2.60	Biotite	Banded gneiss
R-4006	2.591	Biotite	Pegmatite
Nier (1950)	2.59		

The results show an excellent agreement with the value reported by Nier which was measured using the single filament mode of ionization.

iii. Mass Spectrometric Analysis

Instrument

The instrument used in this study was a first order direction focusing 60^{o} sector, 9 inch radius of curveture, solid source mass spectrometer which was built at D.T.M., Carnegie Institution of Washington.

The analyzer tube had two pumping leads, one near the source and the other near the collector and was evacuated by two CEC 40 l/sec mercury diffusion pumps backed up by a Hitachi 100 l/min mechanical pump. Two large cold traps were located between the analyzer tube and the diffusion pumps and were cooled with dry ice.

The vacuum was measured by Penning gauge mounted on the top of each cold trap. Operating pressure was usually $1\sim2 \times 10^{-6}$ mmHg.

A magnetic sweep was employed and scanning was made by rapid switching of the magnetic field. Ion beam was collected on a usual Faraday cup or on a electron multiplier.

In a earlier stage of the study, D.T.M. 9 stage Au-Mg electron multiplier was used and later Mitsubishi 12 stage Cu-Be multiplier replaced this.

The overall voltage 2,750V was supplied to the multiplier from dry batteries. The usual gain of the Mitsubishi multiplier was 2000~3000.

Ion current was amplified by a Cary model 31 or Takeda 84 HS vibrating reed electrometer. $10^9\Omega$ resistor was used for electron multiplier detection and $10^{11}\Omega$ resistor for direct collection.

Ion peaks were recorded on a Honeywell-Brown strip chart recorder which had 1/4 second responce time.

In this investigation, single filament surface emission ion source was used. Sample was placed on a .001 X .020" tantalum ribbon which was spot welded to posts in the ion source. The main parts of the ion source were made of tantalum so that they may be washed in HNO_3.

Isotopic Measurement

In isotope analysis of Sr. cares should be exercised to avoid contamination due to Rb. Because both parent and daughter element have essentially the same mass. Mass 87 due to Rb will interfere the determination 87/86 ratio of Sr sample. Rb contamination in Sr analysis arises from two sources; one is the Rb contained in the Sr sample due to poor chemical separation between Rb and Sr, and the other is due to the ion source itself in the mass spectrometer.

The Rb contamination in the ion source arises also from two sources; one is due to the normal Rb which is contained in the tantalum ribbon, the other is due to the Rb accumlated in the parts of the ion source near the filament from previous analysis. To avoid such contamination in the mass spectrometer, all ion source parts exposed to the filament were cleaned in HNO_3 + 1% HF solution between successive runs.

In addition the filament was outgassed in a outgassing device for several hours by passing electric current through the filament before mounting the sample. After these treatments, no Rb ion was detected at the higher filament current than those normally employed for Sr ion emission.

After the sample was mounted on the filament, the ion source was returned to the mass spectrometer tube and fastened with Allen head bolts. A new aluminum gasket was used for each run to ensure a tight seal.

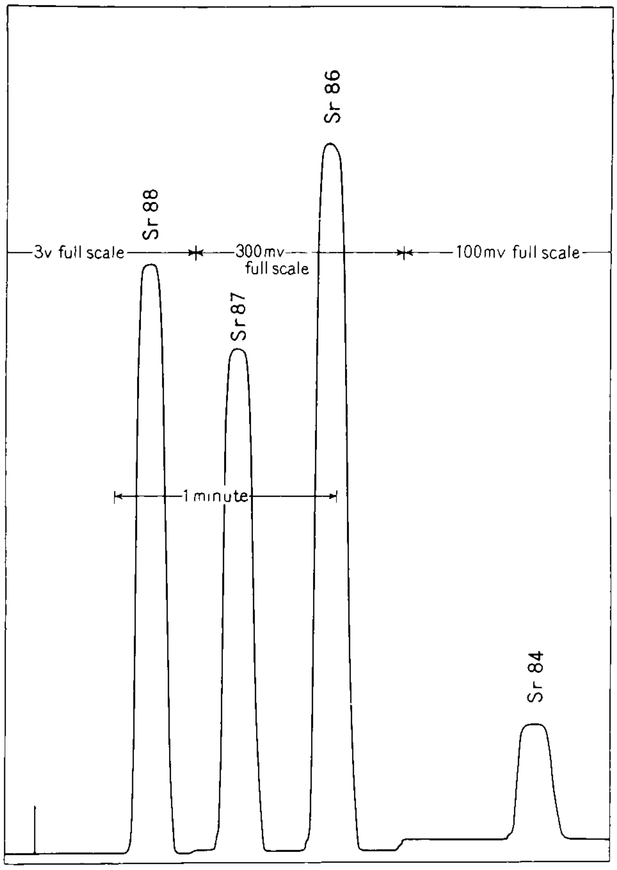
Then the tube was evacuated. Rb analysis was made as soon as the vacuum was lowered to the range of 10^{-6} mmHg. From 10 to 20 scans for 87/85 ratio were recorded.

In Sr analysis, however, the filament current was turned on and the sample was conditioned for overnight at the filament temperature just below that at which Sr ion emission began.

This conditioning burned off the contaminating Rb in the sample and gave most stable ion current. After the pressure had fallen to approximately 1×10^{-6} mmHg, the filament current increased until the emission of Sr ions began to increase spontaneously.

When the peak height was great enough to be in the range, usually more than 100mV range of the electrometer, the ratio 88/86, 87/86 and 86/84 were recorded repeatedly. Usually from 10 to 30 scans for each set were recorded without further change of the filament current. Constant checking of the mass 85 position was made and it was ensured that there was no Rb contamination. A typical spectrum record of Sr isotope is presented in Fig. 4.

Fig. 4.



Spectrum of Sr isotope (R-4303 total rock)

iv. Spike Solutions

The spike solutions used in this study were prepared at the Department of the Terrestrial Magnetism by Dr. G.L.Davis and were calibrated by Drs. L.T. Aldrich and S.R.Hart against shelf solutions.

Sr carbonate enriched in Sr^{86} and Sr^{84} , Rb chloride enriched in Rb^{87} and Potassium chloride enriched in K^{41} were obtained from ORNL.

The Sr spike solution # 3, stored in a 100ml Pyrex flask, contained both Sr^{86} and Sr^{84} This Sr^{86} - Sr^{84} double tracer served to assume how the machine was performing.

The Rb^{87} - K^{41} spike solution#5 contained both Rb^{87} and K^{41} With this spike solution, potassium as well as rubidium was determined by isotope dilution method. These dilute spike solutions were used without further calibration against normal strontium, rubidium and potassium shelf solutions. The concentration and isotopic composition for these spike solutions are as follows:

Sr^{86}- Sr^{84} # 3 spike solution

Sr^{88}	0.003608	mole/g	86/84 = 7.61
Sr^{87}	0.001022	"	87/86 = 0.0549
Sr^{86}	0.01860	"	88/86 = 0.1939
Sr^{84}	0.002443	"	

Rb^{87}- K^{41} # 5 spike solution

Rb = 2.867 g total Rb/g   87/85 17 57

= 0.0329 mole/g

K = 60.87 g total K/g   41/39 = 89.0

= 42.89 g total K/ml

v. Rb-Sr age calculation

The Rb-Sr age was calculated from the following equation

$$t = \frac{1}{\lambda} \ln\left(1 + \frac{Sr^{87*}}{Rb^{87}}\right)$$

where λ is the decay constant of Rb^{87} and Sr^{87*} represents radiogenic component of Sr^{87}

The constants used for calculation are as follows:

Rb^{87}: $= 1.39 \times 10^{-11} yr^{-1}$

$Rb^{85}/Rb^{87} = 2.59$

The isotopic ratio for normal Sr is taken as follows: ✱

$Sr^{88}/Sr^{86} = 8.348$ Sr^{87}/Sr^{86} .708 and $Sr^{86}/Sr^{84} = 17.88$

The amount of rubidium and strontium in the sample were calculated in the following manner.

Rubidium

If in any element Z, there are two isotopes, Z^a and Z^b with ratio $\frac{N^a}{N^b} = A$, we may write the following generalized equations

$$1\,\mu\text{mole } Z^a = a\,\mu g$$

$$1\,\mu\text{mole } Z^b = b\,\mu g$$

$1\,\mu$mole of any element or isotope contains 10^{-6} x Avogadro's number of atoms, thus

$$\frac{\mu\text{mole } Z^a}{\mu\text{mole } Z^b} = \frac{N^a}{N^b}$$

If we have "normal" ratio of $\frac{N^a_{normal}}{N^b_{normal}}$ B and spike ratio $\frac{N^a_{spike}}{N^b_{spike}} = C$

in mixture of two solutions,

$$D = \frac{N^a_{mix}}{N^b_{mix}} = \frac{N^a_{normal} + N^a_{spike}}{N^b_{normal} + N^b_{spike}}$$

$$D\,(N^b_{nor} + N^b_{spike}) = N^a_{nor} + N^a_{spike}$$

$$D\,(N^a_{nor}\frac{1}{B} + N^a_{spike}\frac{1}{C}) = N^a_{nor} + N^a_{spike}$$

$$\therefore\quad N^a_{nor} = N^a_{spike}\frac{B}{C}\left(\frac{C - D}{D - B}\right)$$

Then $\mu\text{mole } Z^a_{nor} = \mu\text{mole } Z^a_{spike}\frac{B}{C}\left(\frac{C - D}{D - B}\right)$

Substituting Z^a for Rb^{87}, then

$$\mu\text{mole } Rb^{87}_{nor} = \mu\text{mole } Rb^{87}_{spike}\frac{B}{C}\left(\frac{C - D}{D - B}\right)$$

while $B = \dfrac{\text{mole } Rb^{87}_{nor}}{\text{mole } Rb^{85}_{nor}} = 0.386$ and $C = \dfrac{\text{mole } Rb^{87}_{spike}}{\text{mole } Rb^{85}_{spike}} = 17.57$

$$\begin{aligned}\mu\text{mole } Rb_{nor} &= \mu\text{mole } Rb^{87}_{nor} + \mu\text{mole } Rb^{85}_{nor}\\ &= \mu\text{mole } Rb^{8}_{nor} + \frac{1}{0.381}\mu\text{mole } Rb^{87}_{nor}\\ &= \mu\text{mole } Rb^{87}_{nor}\left(\frac{1.386}{0.386}\right)\end{aligned}$$

$$\begin{aligned}\mu\text{mole } Rb_{spike} &= \mu\text{mole } Rb^{87}_{spike} + \mu\text{mole } Rb^{85}_{spike}\\ &= \mu\text{mole } Rb^{87}_{spike} + \mu\text{mole } Rb^{87}_{spike}\left(\frac{1}{17.57}\right)\\ &= \mu\text{mole } Rb^{87}_{spike}\left(\frac{18.57}{17.57}\right)\end{aligned}$$

therefore $\mu\text{mole } Rb = \mu\text{mole } Rb_{spike}\cdot\dfrac{1.386}{18.57}\left(\dfrac{17.57 - D}{D - 0.386}\right)$

where D is the measured Rb^{87}/Rb^{85} ratio

Strontium

$$D = \left(\frac{Sr^{88}}{Sr^{86}}\right)\text{measured} = \left(\frac{Sr^{88}}{Sr^{86}}\right)\text{mixture}\quad \frac{\mu\text{mole } Sr^{88}_{nor} + \mu\text{mole } Sr^{88}_{spike}}{\mu\text{mole } Sr^{86}_{nor} + \mu\text{mole } Sr^{86}_{spike}}$$

while

$$\frac{\mu\text{mole } Sr^{88}_{nor}}{\mu\text{mole } Sr^{86}_{nor}} = 8.348 \quad \text{and} \quad \frac{\mu\text{mole } Sr^{88}_{spike}}{\mu\text{mole } Sr^{86}_{spike}} = 0.1939$$

therefore

$$D = \frac{\mu\text{mole } Sr^{86}_{nor} \times 8.348 + \mu\text{mole } Sr^{86}_{spike} \times 0.1939}{\mu\text{mole } Sr^{86}_{nor} + \mu\text{mole } Sr^{86}_{spike}}$$

$$\mu\text{mole } Sr^{86}_{nor} = \mu\text{mole } Sr^{86}_{spike} \left(\frac{D - 0.1939}{8.348 - D}\right)$$

The micromoles of total Sr^{86} in the sample is the sum of the micromoles of Sr^{86}_{normal} and the micromoles of Sr^{86}_{spike}, then

$$\mu\text{mole } Sr^{86}_{total} = \mu\text{mole } Sr^{86}_{normal} + \mu\text{mole } Sr^{86}_{spike}$$

The micromoles of radiogenic Sr^{87} is given by the following equation

$$\mu\text{mole } Sr^{87*} = \mu\text{mole } Sr^{87}_{total} - \mu\text{mole } Sr^{87}_{normal} - \mu\text{mole } Sr^{87}_{spike}$$

where

$$\mu\text{mole } Sr^{87}_{nor} = \left(\frac{Sr^{87}}{Sr^{86}}\right)_{nor} \times \mu\text{mole } Sr^{86}_{nor} \quad \text{and}$$

$$\mu\text{mole } Sr^{87}_{total} = \left(\frac{Sr^{87}}{Sr^{86}}\right)_{measured} \times \mu\text{mole } Sr^{86}_{total}$$

The micromoles of Sr^{84}_{total} is calculated likewise:

$$\mu\text{mole } Sr^{84}_{total} = \frac{1}{\left(\frac{Sr^{86}}{Sr^{84}}\right)_{measured}} \times \mu\text{mole } Sr^{86}_{total}$$

The calculated ratio $\frac{\mu\text{mole } Sr^{86}_{total}}{\mu\text{mole } Sr^{84}_{total}}$ was compared with the measured ratio $\frac{Sr^{86}}{Sr^{84}}$

These two ratio theoretically must coincide with each other; both ratio agreed generally within approximately 1 percent. Thus one can know how machine is performing, comparing these two ratio.

Reproducibility:

Duplicate analyses of rubidium and strontium were made on several samples. For the purpose of evaluating the precision error of an individual analysis, the standard deviation for a single analysis (σ) is most applicable. From the results presented below, the error in the rubidium analyses is thought to be 8 percent at the maximum, while the precision error in determining Sr^{87*} is thought to be the order of 3 percent.

It is believed that the probable error in the Rb-Sr age measurements is 8 percent at the maximum from the duplicate measurements on several specimens.

Duplicate analyses of rubidium and strontium

Specimen No. and Mineral	Rb ppm	E %	$\bar{E}$ %	Sr^{87*} ppm	E %	$\bar{E}$ %
R-4006 Muscovite	1596 1592 1479	4.27	2.47	0.581 0.583	0.24	0.17
R-4304 Biotite	694 715	1.91	1.35	0.316 0.302	3.20	2.27
R-4301 Biotite	410 453	7.06	4.99	0.215 0.225	3.23	2.28
R-4236 Biotite	572 523	6.34	4.48			
R-4118 Biotite	498 468	4.86	3.11			
R-4303 Biotite				0.227 0.235	2.47	1.73
R-4005 Biotite				0.247 0.236	3.20	2.26

where $\sigma = \sqrt[2]{\frac{d^2}{n-1}}$ $E = \frac{\sigma}{M} \times 100$ $\bar{\sigma} = \sqrt[2]{\frac{d^2}{n(n-1)}}$ $\bar{E} = \frac{\bar{\sigma}}{M} \times 100$

* It is assumed that a $SrCO_3$ standard [Eimer and Amend lot 492327] has "normal" Sr isotopic composition. The averages of 8 determinations of this $SrCO_3$ reagent performed recently in this laboratory are:

$Sr^{86}/Sr^{88} = .1198$ $\quad Sr^{87}/Sr^{86}_n = 708$ and $Sr^{86}/Sr^{84} = 17.88$

The Sr^{87}/Sr^{86} ratio for this Sr isotope standard, 0.712, has been reported previously by several workers.(2)(10)(9)

The measurement of isotopic composition of this $SrCO_3$ in this laboratory also yielded the value of 0.712 for the Sr^{87}/Sr^{86} ratio (see Table 9).

However, the revised Sr^{87}/Sr^{86} ratio for this $SrCO_3$ standard was reported recently. which is in the range .708-.709.(8)

Recent re-determination of this $SrCO_3$ reagent in this laboratory also lowered the value of the Sr^{87}/Sr^{86} ratio from .712 to .708, as a result of improved vacuum condition; at the time when the Sr isotopic measurements on a series of unspiked samples were carried out, complete resolution between the larger mass 88 peak and the smaller mass 87 peak was not obtained; the 88 peak tail was enhancing the 87 peak. Therefore, the Sr^{87}/Sr^{86} values in Table may be up to .004 higher than the present day value on the same material.

3. Determination of argon* and potassium

i. Description of fusion system

The argon extraction system used in this laboratory is a flux fusion system essentially the same as described by Wetherill, Tilton, Davis and Aldrich (1956).

Three mercury cut-offs were used to isolate pumping system from fusion system and also to isolate extraction line from purification line.

The pumping system consists of a Nier-type two stage mercury diffusion pump backed up by a fore pump.

The fusion system is constructed by Pyrex glass and mounted on a transite base, which is shown schematically in Fig. 5.

The extraction line consists of a nickel cruicible, Ar^{38} spike, cold traps, CuO trap and pirani vacuum gauge. The nickel cruicible was charged with 40-50 grams of fresh NaOH and was outgassed at 600°-650° C by means of a removal electric furnace. A new aluminum gasket was used for sealing for each run. Two cold traps located each side of CuO trap, were used to freeze out water vapor at liquid nitrogen temperature.

The CuO trap was used to convert H_2 to H_2O, which was outgassed and operated at 500°- 550°C. A glass pirani gauge was used to follow the releasing of the gas from the sample during the fusion.

The purification line consists of a charcoal trap, titanium sponge, sample take-off ampule and pirani gauge.

Titanium sponge filled in a bent quartz tube, was outgassed at 1000°-1100°C and operated at 900°- 950°C. Charcoal trap and sample take-off ampule were outgassed at 450°C. A pirani gauge was used to follow the outgassing of the purification line and the cleaning up of the released gas.

The fusion system, except for the nickel cruicible, is mounted by a oven shell and can be baked by two 1.5KW strip heaters placed on the transite base. The whole system was baked normally at 200°C.

A timing device was used to turn off the heater automatically to allow the system cool to room temperature by morning.

* K-Ar measurements were carried out on eight mineral separates (3 hornblende, 3 biotite and 2 muscovite).

Argon extraction and isotopic measurement of one biotite and one muscovite were made at Tōhoku University by Prof Ueda through the courtesy of Profs. Kawano and Ueda. Argon extractions of three hornblende samples were carried out at the Department of Physics, Osaka University and of the remaining samples at this laboratory. Argon isotopic analyses on these samples were made by static runs using the mass spectrometer at the Osaka University.

The argon extraction systems employed at the laboratories of Tōhoku Univ. and Osaka Univ. were fully described elsewhere.(17)(26)

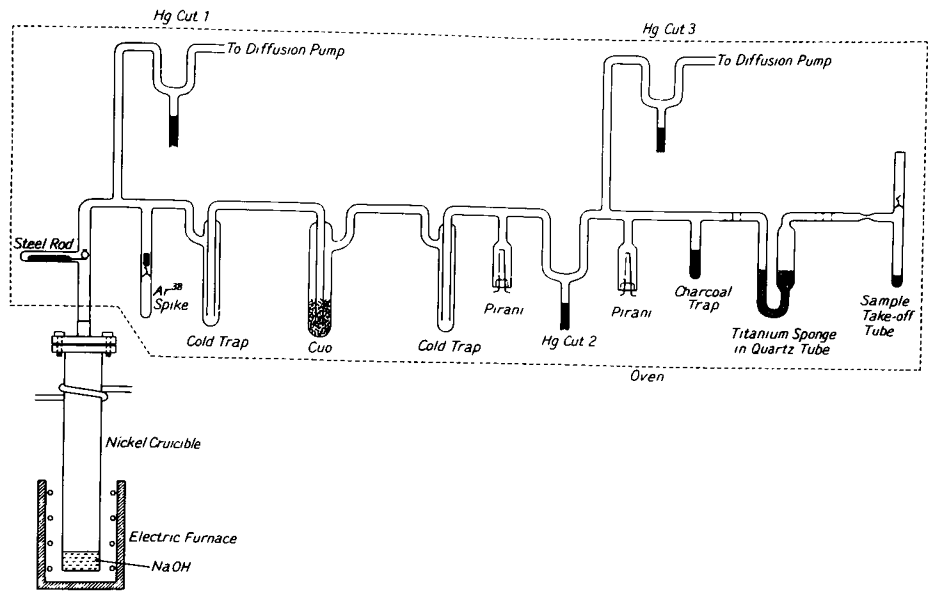


Fig. 5.

Argon extraction system used in this study

ii. Fusion procedure

0.5 to 1 grams of sample were weighed out into a thin Pyrex glass ampule which was sat on a steel rod. Nickel cruicible containing fresh NaOH was attached to the system. Ar^{38} spike and sample take-off ampule were also blown onto the system. Then the system was pumped down and leak tested by tesla sparking. After it was ascertained that there was no leak, oven shell was mounted and the system was baked for outgassing. The system and NaOH were outgassed for 12 hours, usually overnight.

After the system had cooled, the oven shell was removed. The furnace for CuO was tuned on and the CuO was heated to its outgassing temperature.

After 4 hours outgassing, the mercury cut 1 and 2 were raised to isolate the pumping system from the extraction line. Liquid nitrogen was placed around the cold traps. CuO was kept at 500°- 550°C. Then the sample was droped by withdrawing the steel rod with a magnet and the fusion was started

The furnace for titanium sponge, charcoal trap and sample take-off ampule were turned on and they were outgassed at their outgassing temperature.

Temperature of the nickel cruicible was raised slowly to the melting point of NaOH, about 320°C. Usually at 340°C (temperature measured by a thermocouple on the surface of the nickel cruicible), gas release was started. Break-seal of Ar^{38} spike was broken imediately after the first gas release.

Temperature was raised slowly. watching the pirani gauge for increase of the pressure of the released gas. If it is raised rapidly, biotite reacts with NaOH violently and is tend to blast upward.

Once temperature reached about 500°C, it was raised fairly rapidly. The nickel cruicible was kept at 700°C for 3-4 hours. The pressure of the released gas was about 2×10^{-1}mmHg at the maximum throughout the fusion, when CuO worked efficiently. But in few cases the pressure went up as high as 1-2mmHg. Before the completion of the fusion, the furnace for titanium sponge was turned off and allowed to cool to room temperature.

After 3-4 hours fusion, the sample was completely dissolved in NaOH. The nickel cruicible was allowed to cool and by that time the pressure was usually down to the range of 10^{-2}mmHg.

The mercury cut 3 was raised and the purification line was isolated from the pumping system. The furnace for charcoal trap was removed and liquid nitrogen was placed around it.

The mercury cut 2 was then lowered and the gas in the extraction line, was transferred to the purification line and absorbed by the charcoal trap.

Half an hour was enough to absorb all gas in the extraction line. While the transferred gas was absorbed in the charcoal trap, the furnace for the titanium sponge was turned on and the titanium sponge was heated to its operating temperature.

When the titanium sponge was heated to 900°- 950°C, liquid nitrogen was removed from the charcoal trap and the gas was released in the purification line.

The titanium sponge was heated from 1/2 to 1 hour until constant pressure was attained. Then the titanium sponge was allowed to cool slowly to 200°-300°C . The furnace for sample take-off ampule was removed and liquid nitrogen was placed around it. After 20 minutes, the sample take-off ampule was sealed off with a fine flame.

iii. Mass spectrometric analysis

Instrument

The mass spectrometer used for the argon analyses, was a 90° sector field 20cm radius of curveture gas source mass spectrometer at Osaka University.

This instrument was described in detail by Okano et al. (1960). Only brief description will be given here.

The analyzer tube was evacuated by a 300ℓ/sec oil diffusion pump and a mechanical fore pump, through a liquid nitrogen and a dry ice trap.

The normal vacuum attainable was about 5×10^{-9}mmHg measured by a B-A vacuum gauge.

Mitsubishi 12 stage Cu-Be electron multiplier was used for ion detection. The ion current was amplified by a Cary 31 vibrating reed electrometer and the ion peaks were recorded by a Minneapolis Honeywell 1/2" strip chart recorder. Normal operative condition was as follows:

Accelating voltage; 2000V

Total emission current; 100μA

Overall voltage supplied to electron multiplier; 1700V

An all metal bakeable valve was located between the analyzer tube and the pumping lead. Sample gas was introduced into the source region through a needle valve from the gas inlet system.

Isotope measurement

All argon analyses were made by static runs. The analysis was typically performed in the following manner:

The ampule containing Ar sample was blown onto the gas inlet system, which was pumped down and baked for several hours at 200°C.

Then the residual gas in the gas inlet system was analyzed dynamically by scanning from the mass 12 to the mass 45. After it was ascertained that peaks at the mass 36, 38 and 40 were sufficiently small for making static run, the gas inlet system was isolated from the pumping system by means of two greaseless cocks. A cold trap in the gas inlet system was cooled with liquid nitrogen.

Before the argon measurement, background peaks were recorded under static operation. The background peaks from the mass 36 to the mass 40 were scanned 7-8 times. After a series of background spectrum was recorded, the valve was opened and the analyzer tube was evacuated.

When the vacuum recovered to that at which back ground measurement was made, the argon analysis was started. The sample gas in the gas inlet system was introduced through the needle valve into the source region.

The magnet coil current was adjusted so that the top of Ar^{38} peak was recorded on a chart. The needle valve was opened slowly and Ar^{38} peak began to increase. If Ar^{38} peak top reached 60 - 80 divisions of the chart, the needle valve was closed.

Scanning from 36 to 40 was repeated, usually 7 - 8 times. Ar^{36}/Ar^{38} and Ar^{40}/Ar^{38} ratio were obtained through the correction for the background

Ar^{36}, Ar^{38} and Ar^{40} peaks.

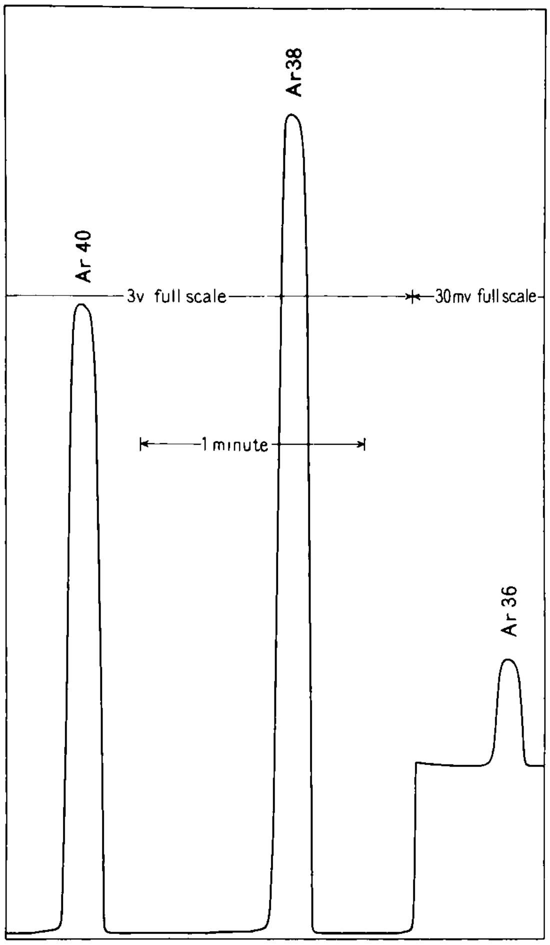


Fig. 6.

A portion of a mass spectrometer record of argon isotope analysis is presented in Fig. 6.

iv. Ar^{38} spike

Two kinds of Ar^{38} spike set were used in this study; one was prepared at Tohoku University by Prof Ueda, which had the following isotopic composition:

lot 10-8-4

Ar^{36}/Ar^{38} 0.00027

Ar^{40}/Ar^{38} = 0.00198

Ar^{38} partial pressure = 0.00429mmHg at 0°C.

The other was prepared at Osaka University, which had the following isotopic composition:

$Ar^{36}/Ar^{38} = 0.00025$

$Ar^{40}/Ar^{38} = 0.00555$

Ar^{38} partial pressure = 0.005135mmHg at $0^{\circ}C$.

The volume of each spike ampule was measured with mercury. Each spike ampule contained approximately 2×10^{-5}cc Ar^{38}

v. Potassium analysis

Potassium was determined for three hornblende samples using flame photometer and for all of mica samples using isotope dilution method.

Flame photometric analyses were carried out by Dr. Ishibashi of Kyushu University. It is believed that the error in potassium analyses with flame photometer is 3 percent or less (private communication, Ishibashi)

From the reproducibility of the results by isotope dilution analyses, the error in the potassium analyses using isotope dilution method is believed to not exceed 5 percent.

A standard biotite M.I.T. B-3203 was analyzed by isotope dilution method to estimate the accuracy of the potassium analysis. This standard biotite yielded 7.58 percent potassium content, which is in good agreement with the reported value 7.61 percent K for this standard biotite (average of 12 analyses).[27]

The K-Ar ages were calculated using the following equation:

$$t = \frac{1}{\lambda_e + \lambda_\beta} \ln \left(1 + \frac{\lambda_e + \lambda_\beta}{\lambda_e} \frac{Ar^{40}}{K^{40}} \right)$$

where $\lambda_e = 0.585 \times 10^{-10}\ yr^{-1}$

λ_β $4.72 \times 10^{-10}\ yr^{-1}$ (5)

II Age measurements on the granitic and metamorphic rocks of the Ryoke metamorphic terrain in the Kinki district

General statement

Age determinations were made, mainly by the Rb-Sr method, on 24 samples collected from the Ryoke metamorphic terrain in the Kinki district.

Biotite, muscovite, hornblende and potassium feldspar were separated from the rock specimens. The Rb-Sr age measurements were carried out on biotite, muscovite and potassium feldspar. But unfortunately, because of high Sr/Rb ratio, the Rb-Sr measurements on potassium feldspars were unsuccessful, except for one sample from pegmatite.

Several K-Ar measurements were also made on biotite, muscovite and hornblende. Along with the analytical data of each district, brief geological settings will be stated, with the exception of the western district which was fully described in the previous chapter.

I. Western district (Ikoma-Kongo district)

Discussion on age measurement

Four granitic rocks and one banded gneiss were collected and analyzed. The ages measured on the rocks of this district are presented in Table 1. The analytical data are also presented in Table 2.

TABLE 1

Age determination from the Ikoma-Kongo district

Sample	Rock	Locality	Mineral	Aparent age (m.y.) K-Ar	Aparent age (m.y.) Rb-Sr
R-2099	Hornblende-biotite granite	South of Mt.Ikoma	Biotite		94
R-2117	Hornblende-biotite granite	South of Mt.Ikoma	Biotite		113
R-2014	Gneissose hornblende-biotite granodiorite	Takayasu	Biotite		98
R-2253	Banded gneiss	Mt.Matsuo	Biotite		162
R-1100	Gneissose hornblende-biotite granodiorite	Hiraiwa	Biotite		103
			Hornblende	115	

The Rb-Sr ages on biotite of the granitic rocks in this district converge into 110-90 m.y. The specimens R-2099 and R-2117 were collected from the hornblende-biotite granite (Yagyu granite). At the exposure where R-2117 was collected, the granite shows typical "Yagyu granite" appearance; the granite is coarse-grained and fairly distinctly foliated, being porphyritic. The specimen R-2099 was collected at the quarry situated directly south of the Ikoma metanorite body. The rock is medium-grained biotite granite with a small amount of phenocrysts of potassium feldspar. The Rb-Sr ages on biotite of these two granites are 113 m.y. and 94 m.y., respectively. There is a slight difference in age between these two granites, but this may not have much meaning; both granites are different phase of the same granite body. R-2014 was collected at Takayasuyama from dark colored, hornblende-biotite gneissose granodiorite which was remarkably foliated. The Rb-Sr age on biotite is 98 m.y. R-1100 was also collected from the hornblende-biotite gneissose granodiorite at Hiraiwa, south of Mt.Nijo. This rock is remarkably foliated, in which granular texture is observed under the microscope. The Rb-Sr age on biotite is 103 m.y. Hornblende was separated from this specimen, on which the K-Ar measurement was made. The K-Ar age 115 m.y. was obtained on this hornblende. The Rb-Sr age on biotite and the K-Ar age on hornblende are in considerably good agreement, indicating that this gneissose granodiorite was emplaced approximately 110 m.y. ago. R-1100 and R-2014 are considered to correspond to the so-called "older" granitic rock. But the result obtained from R-1100 shows that the age on the "older" granitic rock is almost identical with that on the "younger" granitic rock (Yagyu granite). This means that there may not be much intrusion-time-gap between the "older" granitic rocks and the "younger" granitic rocks.

A banded gneiss sample, R-2253, was collected from the Mt.Matsuo banded gneiss block. The Rb-Sr age on biotite 162 m.y. is significantly older than the age of the granitic rocks, which is approximately 110 m.y.- 90 m.y. This result will be discussed later together with the other results of the banded gneiss of other districts.

TABLE 2

Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-2099	Biotite				1.96	0.311	0.69	838
R-2117	Biotite				3.50	0.175	0.42	393
R-2014	Biotite				4.09	0.217	0.43	558
R-1100	Biotite				6.38	0.248	0.36	613
	Hornblende	0.00485	0.66	0.574				
R-2253	Biotite				5.72	0.163	0.29	254

II. Northern district (Kasagi district)

Geological setting

This district is located in the northeast of Nara City and occupies the northern part of the so-called "Yamato plateau". This district has been known as the "Kasagi district" among geologists and has been studied by many investigators, compared with other districts in the Kinki Ryoke metamorphic terrain where no detailed studies have been carried out.

Arita(1949) and Matsumoto(1947) carried out petrographical studies on the rocks in this district. Recently Nakajima(1960) conducted a detailed geological and petrographical study. The geological setting of this district is mainly indebted to the work of Nakajima.

This district comprises several kinds of granitic rocks and various metamorphic rocks of sedimentary origin. In the northern part of this district, low grade metamorphic rocks of sedimentary origin develop widely and grade into unmetamorphosed Palaeozoic formation. A part of the Palaeozoic formation is considered to be middle Permian in age, judging from the fossils contained in the limestone bed.

The metamorphic and granitic rocks in this district are classified by

Nakajima into two groups; the older and the younger.

As to the granitic rocks in this district, Arita distinguished two kinds of granitic rocks; "Koya granite" and "Yagyu granite". He considered that the Koya granite is older than the Yagyu granite, judging from the relationship between the granites and metamorphic rocks.

Nakajima further divided the granitic rocks in this district into six phases, as a result of his field study. The granitic rocks were divided into the following six phases, according to the sequence of intrusions.

1. Sugawa gneissose granodiorite
2. Koya granite
3. Yagyu granite
4. Ideminami granite
5. Ōmine quartz diorite (granodiorite)

Besides these, he further distinguished fine-grained granite, whose intrusion time is not known clearly. Among these granitic rocks, the Sugawa gneissose granodiorite is approximately concordant with the metamorphic rocks in structure and was assumed by Nakajima to have intruded in the "older metamorphism".

The Koya granite was assumed to have intruded from the later stage to the end of the "older metamorphism". The Yagyu granite is most widely distributed in this district. Two blocks are recognized; the Narukawa-Yamashiro block and the Yagyu block. This granite was considered to be the "younger granite", which had intruded after the completion of the "older metamorphism". The Idemimami granite has a close genetic relation with the Yagyu granite and was also considered to be the "younger granite". As has been described previously, this kind of granite is also observed in the biotite granite in the western district.

The Ōmine quartz diorite (granodiorite) was considered to be the youngest intrusive body among the granitic rocks in this district.

The fine-grained granite was assumed to be the "older granite", though much was not known about this. Brief description will be given with each granitic rock.

The sugawa gneissose granodiorite is medium-grained, dark colored and remarkably foliated, in which the direction of the foliation is nearly definite throughout the body. It extends approximately in a sill. Abundant hornblende of dark green variety is contained. Diopside and garnet vein are rarely found.

The Koya granite has two phases; one, distributed in the southern part of Kizu River, is dark colored, medium- to fine-grained garnet bearing biotite granite. This granite is usually foliated and is greatly varied in its rock facies. It trends N40°W, forming a pluton, which is subconcordant with the metamorphic rocks in structure. The other, lying north of Kizu River, is medium-grained, leucocratic biotite granite, being non-foliated. Small porphyroblasts of potassium feldspar develop in this granite. It intrudes into the weakly metamorphosed Palaeozoic formation and gives contact metamorphism to it. Although these two phases are considerably different in their appearances, they are assumed to form a single granite body.

The Yagyu granite is coarse-grained, hornblend-biotite leucocratic granite. Generally this granite contains phenocrysts of potassium feldspar and looks porphyritic. Foliation is weak in general, but in some exposures, it is considerably foliated. This granite is a part of a very large basin-shaped batholith, located in the northern part of Ueno City.

The Ōmine quartz diorite is fine- to medium-grained, non-foliated hornblende-biotite quartz diorite. This rock forms a small stock, intruding into the Palaeozoic formation. The fine-grained granite is in general garnet bearing two mica granite, although the content of muscovite is remarkably variable. Usually, it is intimately associated with the banded gneiss.

Discussion on age measurement

Seven specimens were collected and analyzed. The ages measured with the rocks of this district are presented in Table 3 and the analytical data are presented in Table 4.

The specimens were collected from the following rock units.

Biotite granite (Koya granite): R-4302, R-4304 The former was collected from the non-foliated phase, lying north of Kizu River and the latter, from the gneissose granite phase, south of Kizu River.

Hornblende-biotite granite (Yagyu granite): R-4188, R-4303 The former was collected from the Narukawa-Yamashiro body and the latter from the Yagyu block.

Hornblende-biotite gneissose granodiorite (Sugawa gneissose granodiorite): R-4286

Hornblende-biotite quartz diorite (Ōmine quartz diorite): R-4301
Fine-grained quartz diorite: R-4226

TABLE 3

Age determination from the Kasagi district

Sample	Rock	Locality	Mineral	Aparent age (m.y.) K-Ar	Rb-Sr
R-4301	Hornblende-biotite quartz diorite	Ōmine	Biotite		130[a]
R-4302	Biotite granite	North of Koya	Biotite		96
R-4304	Gneissose biotite granite	Nakamura	Biotite		111[b]
R-4188	Hornblende-biotite granite	Narukawa	Biotite	69	86
			Hornblende	146	
R-4286	Gneissose hornblende-biotite granodiorite	Sukawa	Biotite		91
R-4226	Hornblende-biotite quartz diorite	Northwest of Sukawa	Biotite		111
R-4303	Hornblende-biotite granite	Ōgawara	Biotite		156

a: the mean of duplicate measurements 133 and 126

b: the mean of duplicate measurements 106 and 116

Age measurements obtained by the Rb-Sr method on biotites of six granitic rocks range 130 m.y.- 86 m.y., except for R-4303.

No distinct age-gap is observed among the Sugawa gneissose granodiorite, the Koya granite and the Yagyu granite, as seen in Table 3, although Arita and Nakajima distinguished the "older" and the "younger" granitic rocks.

With the specimen R-4188, the K-Ar age measurements were also carried out on biotite and hornblende. The results show somewhat complicated age patterns. The K-Ar age on biotite yielded fairly young age 69 m.y., which is discordant with the Rb-Sr ages on biotites of the granitic rocks which are usually 110 m.y.-90 m.y. Shibata et al. (1961) reported the K-Ar age on biotite from the Inagawa granite, indicating approximately 70 m.y. age. The Inagawa granite is coarse-grained hornblende-biotite granite, occurring in the northwestern region of the Ryoke metamorphic terrain in the Chubu district.

According to Katada et al. (1959) this granite is considered to correspond to the Yagyu granite in the Kinki district. The Inagawa granite develops in a batholith shape on the north western margin of the metamorphic terrain, from the banded gneiss zone to the low grade metamorphosed sedimentary rock zone. All these observations are quite similar to those on the Yagyu granite.

The K-Ar age obtained on R-4188 is in good agreement with that obtained on the Inagawa granite. On the other hand, the K-Ar age on hornblende of R-4188 is highly discordant with the K-Ar and Rb-Sr age on biotite of this specimen. Judging from the geological considerations on this granite, the K-Ar age on hornblende 146m.y. may not represent the real age of the emplacement of the Yagyu granite; firstly, the Yagyu granite, having nearly N-S trend, intrudes in the region where the metamorphic rocks and gneissose granodiorite develop with nearly E-W trend.

This means that the Yagyu granite intruded discordantly with the structures of the metamorphic rocks and gneissose granodiorite. Undoubtly it cuts the structure of the metamorphic rocks. Consequently this granite may not be far older in age than the metamorphic rocks and gneissose granodiorite which are assumed to have been produced approximately 110-90 m.y. ago.

Secondly, the Yagyu granite grades into the "Cretaceous granite" without distinct boundary, for example in the northeastern region of Kasagi.

The Hiei granite which is considered to be the "Cretaceous granite", is dated 90 m.y. by Hayase (1961). Even if there might exist a time-gap in the emplacement between the Yagyu granite and the Hiei granite, it may be small. Consequently the time of the emplacement of the Yagyu granite is assumed to be in the range 110-90 m.y., not so far from 90 m.y. The Rb-Sr age on biotite 86 m.y. is preferred for the age of the emplacement of this granite. As to the discordant K-Ar age 146 m.y. on hornblende of R-4188, the author considers as follows; In spite of the fact that the Yagyu granite generally contains a small amount of hornblende , the granite body from which R-4188 was collected contains a fairly large amount of hornblende.

In the northeastern region of Ueno City, the hornblende-biotite granite develops; this can be correlated to the Yagyu granite from the similarity in the rock facies. This granite body contains a considerably large amount of basic inclusions, ranging from metadiabasic to quartz dioritic rock. This fact probably indicate the existence of the reaction between this granite magma and the pre-existing basic rocks.

Judging from the similarity in the rock phase between the granite mentioned above and the Yagyu granite, the granite from which the specimen R-4188 was collected may have been contaminated with the pre-existing basic rocks. The possibility that the hornblende contained excess Ar^{40}

is considered.

The Rb-Sr age 130 m.y. is obtained on biotite of the Ōmine quartz diorite, which is considerably older than the Rb-Sr ages on biotites of the granitic rocks in this district. Judging from the fact that this quartz diorite intrudes into the Palaeozoic formation in shape of stock and gives contact metamorphism to it, the Rb-Sr age 130 m.y. may indicate the time of the emplacement of this quartz diorite.

That the location of the quartz diorite is isolated from any other granitic rock in this district and that this rock is quartz dioritic in nature, may indicate the fact that the quartz diorite magma had no relationship with other granitic magma in this district.

In connection with this rock, small quartz diorite masses , for example the Kurama quartz diorite, near Kyoto City, are developed in the Palaeozoic formation (Tamba zone) These quartz diorites have been considered by geologists to be related to the granite developing around the quartz diorite masses; these quartz diorites are approximately contemporaneous with the granite. The result obtained in this study, however, suggests that the quartz diorite masses in Tamba zone may have genetical relation with the Ōmine quartz diorite in this district and may have been an intrusion preceding that of the granite developing around the quartz diorite masses.

These quartz diorites, the author considers, may be related to the diabase and the noritic rock which intruded into the Ryoke metamorphic terrain.

The Rb-Sr age on biotite 156 m.y.,obtained from R-4303, is open to question; this specimen was collected at a large quarry situated 1km south of the Ōgawara station, Kansai Line. The specimen looks quite fresh in appearance and biotite shows no sign of alteration by microscopic observation.

But at the quarry, quartz was observed to be stained to pale reddish-brown color in a considerable part of the granite exposure. This fact suggests that the granite may have suffered alteration by hydrothermal solution.

Consequently this was discarded from the interpretation. R-4226 was collected from the quartz dioritic rock which is considered to be a hybrid rock derived from intrusive basic rock.

The Rb-Sr age on biotite is 111 m.y., which is approximately concordant with these obtained on the granitic rocks.

TABLE 4

Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Pb ppm
R-4301	Biotite				26.26	0.215	0.11	410
					30.67	0.225	0.10	453
R-4302	Biotite				8.32	0.339	0.37	893
R-4304	Biotite				49.68	0.316	0.084	694
					43.46	0.302	0.091	715
R-4188	Biotite	0.0346	0.77	6.93	6.63	0.171	0.26	498
								468
	Hornblende	0.00531	0.76	0.490				
R-4286	Biotite				2.53	0.206	0.53	572
								523
R-4226	Biotite				6.28	0.148	0.25	337
R-4303	Biotite				5.80	0.235	0.37	383
					6.41	0.227	0.34	

III. Middle district (Nara-Sakurai district)

Geological setting

This district is located in the east of Nara basin and trends from north to south. This area, comprising the western margin of the "Yamato plateau" corresponds to the southern extension of the Kasagi district and to the western extension of the Ikoma-Kongo district.

A reconnaissance study was made on this area by Nakajima et al. (1956). More recently, this district was fully investigated by Yoshizawa et al. (1965b). This district comprises mainly granitic rocks, basic metamorphic rocks and metamorphic rocks of sedimentary origin.

The eastern part of this district is covered widely by the Muro volcanic rocks and sediments in Tertiary age. Generally speaking, the northern part of this district is occupied by banded gneiss and fine-grained granite, the central part by granitic rocks and basic metamorphic rocks and the southern part by gneissose granodiorite.

The banded gneiss (Tahara-Takamado block) develops widely in the eastern part of Nara City, having a complex folding structure. This banded gneiss block is assumed to be the western extension of the banded gneiss block which constitutes the Kasatori mountain range in the southeast of Ueno City.

In the northern and eastern region of the Tahara-Takamado banded gneiss block, fine-grained granite develops widely. Especially the fine-grained granite block located in the eastern region of the banded gneiss block, constitutes the largest block among the fine-grained granite masses in the Kinki Ryoke metamorphic terrain.

In the southern region of the banded gneiss block, hornblende-biotite granite which is presumably equivalent to the Yagyu granite, develops widely, although this granite contains a considerably large amount of basic rock inclusions of various sizes, differing from the yagyu granite which is considerably scanty in this kind of inclusions.

This granite reveals a S-shaped fold structure. But this fold structure is considered to show a sort of flow structure which was formed at the intrusion of this granite.

A large metanorite block, similar to the Ikoma metanorite body, occurs at Mt.Miwa, trending approximately N70°W.

Around Sakurai City. the hornblende-biotite gneissose granodiorite remarkably foliated, is widely distributed. In the southern region of the gneissose granodiorite, the hornblende-biotite granodiorite develops;which is equivalent to the granodiorite of Mt.Kongo area, extending to the "Median tectonic Zone".

A large pegmatite, ranging 1km $\times$ 1km wide, occurs in the vicinity of Nara City, intruding into the basic metamorphic rock body. This pegmatite has been mined for raw materials for glass industry. It may have derived from the Yagyu granite developing in this region. Brief descriptions, except for the basic metamorphic rocks from which no specimens were taken.

1. Banded gneiss [Tahara-Takamado block]

This banded gneiss block consists of psammitic and pelitic banded gneiss containing sillimanite in the case of the pelitic gneiss, which can often be recognized easilv with the naked eye. The mineral assemblage in the pelitic gneiss is almost identical with that of Mt.Matsuo block. A large amount of graphite is contained in the pelitic gneiss.

2. Fine-grained granite

Fine-grained granite, when closely associated with the banded gneiss, usually becomes garnet bearing two mica granite. In the north of Mt.Miwa the two mica granite is remarkably foliated and is concordant with the accompanying banded gneiss in structure. At Fukagawa, where R-4305 was collected, this granite is a fine-grained biotite granite which is non-foliated and quite homogeneous in rock facies throughout the body.

3. Hornblende-biotite granite

Although the typical Yagyu granite is coarse-grained and fairly homogeneous in its appearance, the granite in this district is considerably varied in its rock facies. Generally it is coarse- to medium-grained and weakly foliated. The granite occasionally turns into medium-grained biotite granite, when it approachs a large basic rock body. R-3335 was collected from this phase.

4. Hornblende-biotite gneissose granodiorite

This rock is dark colored, remarkably foliated and contains a large amount of hornblende. It is quite similar to the gneissose granodiorite occurring at Hiraiwa in the western district.

5. Pegmatite

The pegmatite found at Obara in the east of Sakurai is small in its scale and intrudes into the fine-grained granite which is quite varied in its rock facies. The minerals contained in this pegmatite are muscovite, microcline and quartz. The pegmatite found at Takai consists of biotite, muscovite, microcline, garnet and quartz. Biotite is of green variety. Both muscovite and biotite are typical "book mica".

Discussion on age measurement

Seven samples were collected and analyzed. The results of the age determinations and the data are presented in tables 5 and 6, respectively.

A suite of pegmatitic minerals were obtained from the pegmatite mine at Takai. Both muscovite and biotite are large crystals, reaching to 5~8cm in diameter. Microcline is a good shaped crystal, approximately 15cm long and 8cm wide at the maximum, showing perthite texture under the microscope.

It is commonly considered that mostly reliable ages are those measured on pegmatitic minerals. The minerals of the Takai pegmatite are highly radio genic in Sr^{87} as is seen in Table 6. Consequently it is expected that a high precision of determination could be achieved.

The Rb-Sr ages on microcline and muscovite of the Takai pegmatite are 95 m.y. and 93 m.y. respectively, which are in excellent agreement.

TABLE 5

Age determination from the Nara-Sakurai district

Sample	Rock	Locality	Mineral	Apparent age (m.y.) K-Ar	Rb-Sr
R-4006	Pegmatite	Takai	Biotite		72
			Muscovite		93
			Potassium feldspar		95
R-4005	Banded gneiss	Takamadoyama	Biotite	72	101
			Muscovite	97	162
R-4305	Fine-grained granite	Fukagawa	Biotite		105
R-3662	Gneissose biotite granodiorite	North of Mt.Miwa	Biotite		95
R-3335	Hornblende-biotite granite	North of Hase	Biotite		109
R-4311	Pegmatite	Obara	Muscovite		71
R-4300	Gneissose hornblende-biotite granodiorite	Asako	Biotite		106
			Hornblende	131	

The concordant pegmatite ages are interpreted as both the age of injection of the pegmatite and the age of the end of metamorphism and plutonism of the terrain, because the pegmatites presumably were emplaced near the end of the metamorphism and plutonism.

Thus the concordant Rb-Sr ages obtained on the microcline and muscovite of the Takai pegmatite indicate that the metamorphism and plutonic activity had ended approximately 90 m.y. ago in the Ryoke metamorphic terrain in the Kinki district.

One more pegmatite sample collected at Obara yielded the Rb-Sr age 72 m.y. on muscovite. This age is slightly younger than that of the Takai pegmatite. It is assumed that the pegmatite activities in this terrain had continued up to approximately 70 m.y. ago, although they may not have been intensive.

The Rb-Sr age on biotite of the Takai pegmatite is 72 m.y., which is slightly discordant with those on other co-genetic minerals. A quite similar phenomenon has been reported by Hayase (1961). He measured the Rb-Sr ages on biotite and muscovite of the pegmatite, collected at Mikawamiyazaki, Aichi Prefecture, in the Ryoke metamorphic terrain in the Chubu district and obtained the Rb-Sr age 101 m.y. on muscovite and 40 m.y. on biotite.

More recently, Zartman (1964) reported anomalously low Rb-Sr ages on pegmatitic biotite of the Lone Grove granitic pluton in the Llano Uplift, Texas. The average Rb-Sr age on microcline, muscovite and biotite of the granitic rocks of the Lone Grove pluton is 1020 m.y., while the Rb-Sr ages range 955 m.y. to 655 m.y. for the biotite in the pegmatite.

Co-genetic microcline from the pegmatite yielded normal Rb-Sr age. As for the low Rb-Sr age on pegmatitic biotite, it is most probable that the loss of daughter element has produced these low Rb-Sr ages. However, the mechanism responsible for these low Rb-Sr age is not known exactly.

He suggested it is possible for the rubidium so to distort the crystal lattice that the mineral becomes extremely unstable to strontium migration, from the fact that the biotite have highest rubidium content.

It may be noted that the biotite in the Takai pegmatite has very high r rubidium content compared with the co-genetic microcline and muscovite.

The Rb-Sr ages on biotites of four granitic rocks in this district are well summarized to 115-95 m.y. R-3662, on which the Rb-Sr age 95 m.y. was obtained, is remarkably foliated biotite gneissose granodiorite. Garnet veins are often observed to develop in this granodiorite.

R-4300 was collected from the hornblende-biotite gneissose granodiorite which is considered to be the eastern extension of the Hiraiwa gneissose granodiorite in the western district. The K-Ar age 131 m.y. on hornblende of R-4300 is slightly discordant with the Rb-Sr age 106 m.y. on co-existing biotite. This K-Ar age on the hornblende may be interpreted as the maximum age of the granodiorite emplacement.

The K-Ar age and Rb-Sr ages on biotite and muscovite of the banded gneiss sample R-4005, revealed discordant age pattern. The discussion about the results will be given together with those obtained with the eastern district.

TABLE 6

Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-4006	Biotite				3.21	2.420	0.92	7630
	Muscovite				2.66	0.581	0.76	1596
					2.69	0.583	0.76	1592
								1479
	K-feldspar				1.46	0.458	0.82	1224
R-4005	Biotite	0.0391	0.86	7.53	2.51	0.247	0.59	622
					3.16	0.236	0.52	
	Muscovite	0.0569	0.74	8.22	28.41	0.169	0.077	266
R-4305	Biotite				31.09	0.238	0.099	574
R-3662	Biotite				2.38	0.213	0.56	569
R-3335	Biotite				3.05	0.208	0.49	485
R-4311	Muscovite				1.12	0.771	0.83	2764
R-4300	Biotite				5.47	0.193	0.33	467
	Hornblende	0.00442	0.63	0.454				

Eastern district (Ueno-Nabari district)

Geological setting

In the southeastern region of Ueno City, a large area of metamorphic rocks of sedimentary origin develops. This metamorphic rock block forming the Nunobiki mountain range, runs nearly N-S and is the largest metamorphic sedimentary rock block exposed in the whole Kinki district. A large part of the metamorphic rocks consists of banded gneiss. The northern part of the block consists of schistose hornfels. Most of the banded gneiss in this block is derived from psammitic sediments, interbeded with pelitic sediments.

In general, the mineral assemblage observed in the pelitic banded gneiss is as follows: sillimanite-cordierite-garnet-biotite-muscovite-potassium-feldspar-plagioclase-quartz

In the interior of this metamorphic rock block, no granitic rocks were observed to intrude, except for fine-grained granites of small scale.

Consequently it is assumed that this banded gneiss block is least affected by the granitic intrusions, among those in the Kinki district. The granite exposure nearest to the banded gneiss block, is approximately 8km aprt from this block. Two banded gneiss bodies from which R-4307 and R-4306 were collected, occur near Joryu and Nagase respectively, in the eastern region of Nabari City. They both occur in the hornblende-biotite gneissose granodiorite which is distributed widely in this region.

No granite such as Yagyu granite develops in this region, though fine-grained granite is distributed considerably.

Discussion on age measurement

Five banded gneiss samples, all of which are sillimanite gneiss, were collected from this district. The age measured in this district and the analytical data are presented in tables 7 and 8.

R-4308, R-4309 and R-4310 were collected from the Nunobiki banded gneiss block, which was chosen as the location for sample collecting to get specimens free from the influence of granitic intrusion; this block consists almost entirely of the banded gneiss in which effects of the granitic intrusion are expected to be slightest.

As is shown elsewhere (1965b), however, the banded gneiss block as a whole has a low angle dipping. As a result, although the present exposure on the surface, looks quite vast horizontally, the vertical thickness of the banded gneiss body may not be large. Granites may exist beneath the banded gneiss, not so far from it, although the granite exposure occurs as far as 8km apart from the banded gneiss body. Consequently, it is assumed that the banded gneiss body have been influenced by granites more or less.

TABLE 7

Age determination from the Ueno-Nabari district

Sample	Rock	Locality	Mineral	Apparent age (m.y.) K-Ar	Apparent age (m.y.) Rb-Sr
R-4306	Banded gneiss	Nagase	Biotite		181
R-4307	Banded gneiss	Joryu	Biotite		103
R-4308	Banded gneiss	Nunobiki	Biotite		108
R-4309	Banded gneiss	Nunobiki	Biotite	71	192
			Muscovite	61	231
R-4310	Banded gneiss	Nunobiki	Biotite		107

The K-Ar age measurements on biotite and co-existing muscovite of R-4309 indicate 71 m.y. and 61 m.y. respectively, which are in good agreement with each other. On the other hand, they are discordant with the Rb-Sr age on both biotite and muscovite of this specimen; the K-Ar ages are considerably younger than the Rb-Sr ages on both the granitic rocks and the banded gneiss in this district and others. To account for the result, the following two possibilities may be considered:

1. The K-Ar age on this sample reflects only the "cooling history" of the banded gneiss; the banded gneiss had uplifted 60-70 m.y. ago. Until that time, the banded gneiss had been in high temperature, sitting in the deeper zone, enough to expel the accumlated Ar^{40} The K-Ar age may represent the time elapsed since, by rapid uplifting, the temperature had been lowered to a degree at which no more Ar^{40} liberation occurred.

2. The banded gneiss, now exposed on the surface, has been affected with thermal influence by some granitic activities. The temperature of the banded gneiss is considered to have been raised high enough to diffuse the Ar^{40} from the minerals.

As to these two possibilities, the author considers as follows:

The K-Ar ages on muscovite and co-existing biotite from two banded gneiss specimens, R-4309 and R-4005,are approximately 70-60 m.y., except for one muscovite of R-4005. These results are practically identical to the K-Ar age 69 m.y. on biotite of the Yagyu granite (R-4188). In the northwestern part of the Ryoke metamprphic terrain in the Chūbu district, the Inagawa granite and the Naegi granite develop widelv, as mentioned previously.

Shibata et al. reported the K-Ar age measurements on these granites. The K-Ar age on biotite of the Naegi granite is 64-68 m.y., whereas that from the Inagawa granite is 63-72 m.y., indicating seemingly no difference between the time of the emplacement of these two granites.

As to the geological relation between the Inagawa granite and the Naegi granite, they stated, judging from their relation to the Nohi rhyolite, ". .. this (Nohi rhyolite) is a thick volcanic formation, consisting mainly of welded rhyolitic tuff and is distributed over a wide area to the north west of the Ryoke belt. At its southern margin, the Nohi rhyolite comes into contact with members of the Ryoke suit where it covers uncomformablv the Inagawa granite. In many localities, however, the rhyolite is intruded by the Naegi granite, which leads to the conclusion that there is difference in age between the Inagawa and Naegi granites and that the former is the older of the two." Judging from these geological relations quoted above, it is assumed that the K-Ar age of the Inagawa granite may represent the time of the granitic activity which occurred approximately 60-70 m.y. ago, as shown by the intrusion of the Naegi granite; biotite may have lost radiogenic Ar^{40} through the diffusion by the thermal event which had occurred 60-70 m.y. ago. According to Katada et al. (1959), the Inagawa granite is corrlated to the Yagyu granite in the Kinki district. The Naegi granite is a typical shallow emplaced granite body and may be correlated to the Tanokami and Suzuka granite in the Kinki district, from their petrographical similarities. That the K-Ar age on the Yagyu granite is approximately identical with those on the Naegi and Inagawa granites, may indicate that there existed a granitic activity which emplaced the Naegi granite in the Chūbu district and the Tanokami-Suzuka-Hira granites in the Kinki district.

Thus the K-Ar ages obtained from the Nunobiki banded gneiss block may also indicate the thermal event which had occurred 70-60 m.y. ago.

TABLE 8

Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-4306	Biotite				8.36	0.208	0.26	291
R-4307	Biotite				6.53	0.163	0.26	404
R-4308	Biotite				5.60	0.238	0.38	559
R-4309	Biotite	0.0407	0.86	7.91	6.06	0.190	0.31	251
	Muscovite	0.0406	0.87	9.16	40.72	0.200	0.066	220
R-4310	Biotite				4.52	0.211	0.40	500

Total rock analyses

Total rock analyses on the granitic rocks and the banded **gneisses were attempted.** **The** rock specimens usually fist-sized, **were crushed in a steel mortar and sieved** to pass through 100 mesh **screen. About 1 gram of the powdered sample was** taken and treated with the identical **chemical procedure** as the **mineral samples,** except that it was not **spiked.**

The isotopic composition of reagent $Sr(NO_3)_2$ **[Merck G.R.] was measured periodically** during the course of the study **and the performance of the** isotopic analyses on unspiked total rock samples **were monitored.**

In the later stage of the study, a strontium isotope **standard [$SrCO_3$ Eimer and Amend lot No.** 492327] **was supplied by Dr. L.T.Aldrich of DTM and was also measured** for its isotopic **composition. The results of the** isotopic analyses **made** on both $Sr(NO_3)_2$ and $SrCO_3$ **reagents are presented in Table** 9.

TABLE 9

Isotopic abundance of Merck G.R. $Sr(NO_3)_2$

	86/88	87/86	$87/86_n$*	Date
1.	.1193	.715	.715	5/22/63
2.	.1191	.714	.713	6/1/63
3.	.1190	.714	.713	11/4/63
4.	.1205	.714	.717	11/2/63
5.	.1193	.716	.716	1/9/64
6.	.1195	.713	.713	1/8/64
Mean	.1195	.714	.715	
	$\sigma = \pm.0002$	$\sigma = \pm.001$	$\sigma = \pm.001$	

Table 9 Continued

Isotopic abundance of $SrCO_3$ (Eimer and Amend lot. 492327)

	86/88	87/86	$87/86_n$*	Date
1.	.1206	.707	.711	2/18/64
2.	.1215	.705	.711	2/20/64
3.	.1206	.707	.711	2/24/64
4.	.1204	.710	.713	2/22/64
5.	.1190	.713	.712	2/26/64
Mean	.1204	.708	.712	

* The measured Sr^{87}/Sr^{86} ratios were corrected by adjusting the Sr^{86}/Sr^{88} ratios to 0.1194 and the Sr^{87}/Sr^{86} ratios by half that amount.

The Sr^{87}/Sr^{86} ratio on four granitic rocks and four banded gneisses have been measured to test the feasibility of making age measurements by the total rock method. The analytical results are presented in Table 10.

The principle of this method is based on the assumption that rock as a whole may remain in closed system with respect to radiogenic Sr^{87*}; that means Sr^{87*} tends to remain in the rock as a whole even if minerals are in open system to Sr^{87*} Thus the total rock Rb-Sr age could be highly informative, if they were obtained on several different lithologic phases of the same rock body in which they are of different Rb/Sr ratio.

It is essential in the total rock Rb-Sr age measurement to know the initial Sr^{87}/Sr^{86} ratio in the system. Consequently, for this method to be successful, the following conditions must be fulfiled; spreads of the Sr^{87}/Sr^{86} ratio and Rb/Sr ratio are obtained with a number of samples of same rock body, sufficient to construct a isochron from which the initial Sr^{87}/Sr^{86} ratio is determined.

But unfortunately, favorable Sr^{87}/Sr^{86} ratios with sufficient spreads were not obtained with the analyzed samples: The spread in the Sr^{87}/Sr^{86} ratio is so small that no precise age is expected to be obtained,

TABLE 10

Sr isotope analyses on total rock samples

Granitic rock

Sample	Locality	86/88	87/86	$87/86_n$	Date
R-4301	Omine	.1184	.7076	.7046	1/20/64
R-4286	Sukawa	.1195	.7118	.7121	1/24/64
R-4303	Ogawara	.1198	.7149	.7161	1/21/64
R-4305	Fukagawa	.1177	.7125	.7074	1/25/64

Banded gneiss

Sample	Locality	86/88	87/86	$87/86_n$	Date
R-2253	Matsuo-yama	.1189	.7248	.7233	1/10/64
R-4005	Takamado-yama	.1208	.7218	.7261	1/15/64
R-4306	Nagase	.1204	.7229	.7259	1/10/64
R-4307	Joryu	.1203	.716	.719	1/14/64

Along with the isotopic analyses of strontium using mass spectrometer, semi-quantitative X-ray fluorescence analyses were carried out on a number of total rock samples to estimate their Rb/Sr ratio. The analyses were made on a Norelco X-ray spectrometer with a fluorescence attachment.

The experimental conditions were as follows:

Norelco X-ray spectrometer with W-target tube
Tube run at 50KV 30mA — GM Tube detector
LiF analyzing crystal — Scanning time 1°/min
.005 x 4" source and receiving collimator

Typical spectrum recorded are presented in Fig. 7. The X-ray fluorescence study revealed unfavorable Rb/Sr ratio; the samples analyzed usually contained a large amount of strontium compared with rubidium, the Rb/Sr ratio being small. Thus high content of strontium in these granitic rocks made the total rock analyses unsuccessful.

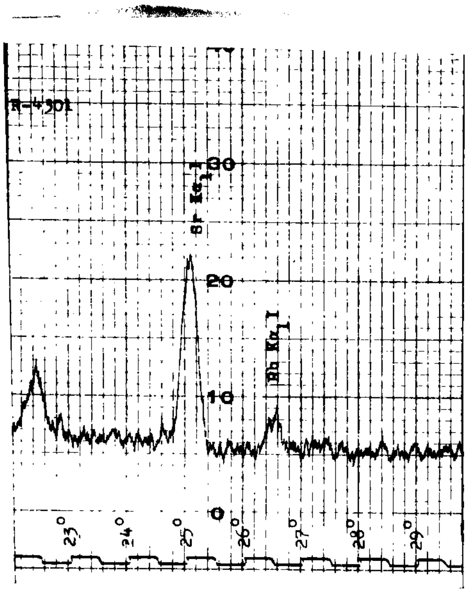
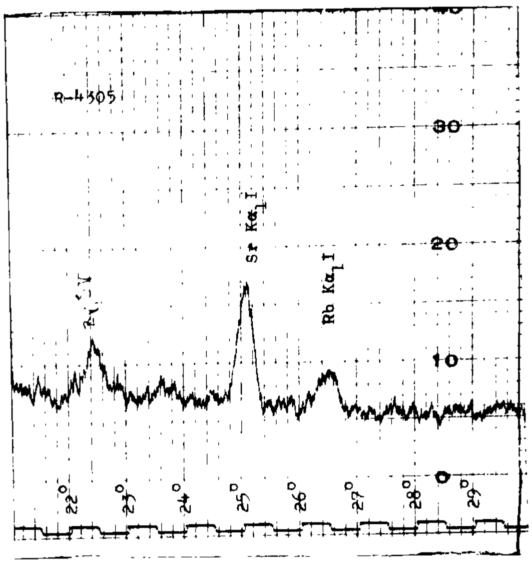


Fig. 7



X-ray fluorescence chart of total rock samples

The Sr^{87}/Sr^{86} ratios in potassium feldspars which were separated from several rock specimens were measured to test the possibility of the use of this mineral for the Rb-Sr age measurement. The results are presented in Table 11. The Sr^{87}/Sr^{86} ratio is expected to be considerably high as a result of enrichment of radiogenic Sr^{87}, if potassium feldspar had not contained much "normal" strontium compared with rubidium.

The Sr^{87}/Sr^{86} ratios measured on four potassium feldspars are very close to the Sr^{87}/Sr^{86} ratio of "normal" strontium, as a result of high content of "normal" strontium, compared with rubidium. Thus the enrichment of radiogenic Sr^{87} was masked by a large amount of "normal" strontium in these potassium feldspars. No Rb-Sr age determinations were carried out on potassium feldspars, except for one pegmatitic potassium feldspar which contained only small amount of "normal" strontium and had a high Sr^{87}/Sr^{86} ratio.

TABLE 11

Sr isotope analyses on potassium feldspar

Sample	Locality	86/88	87/86	$87/86_n$	Date
R-2099	South of Mt.Ikoma	.1178	.718	.713	12/14/63
R-2117	South of Mt.Ikoma	.1196	.712	.713	12/12/63
R-3335	North of Hase	.1189	.718	.716	12/13/63
R-4006	Takamado-yama	.1191	.717	.716	12/11/63

Discussion

The results of the present study indicate that the metamorphism and the plutonic activity in the Ryoke metamorphic terrain had occurred almost throughout the Cretaceous period ranging from 130 m.y. to 70 m.y., culminating in 110-90 m.y. in which most of the metamorphic rocks were produced and the granitic rocks were emplaced.

As to the granitic rocks in the Ryoke metamorphic terrain, the opinion has been prevailing that two distinct different igneous intrusions in age had taken place in this terrain. The granitic rocks in this terrain thus have been divided into two groups; the "older" and the "younger"

The Rb-Sr ages on biotite from several kinds of granitic rocks in the western part of the Kinki Ryoke metamorphic terrain are summarized in Table 12

TABLE 12

The Rb-Sr age of the granitic rocks in the western part of the Kinki Ryoke metamorphic terrain

"younger" granitic rock			"older" granitic rock		
Sample	Locality	age(m.y.)	Sample	Locality	age(m.y.)
R-4188	Narukawa	86	R-2014	Takayasu	98
R-2099	South of Mt.Ikoma	94	R-1100	Hiraiwa	103
			R-4304	Nakamura	111
R-2117	South of Mt.Ikoma	113	R-4302	North of Koya	96
R-3335	North of Hase	109	R-4286	Sukawa	91
			R-4305	Fukagawa	105
			R-4300	Asako	106
			R-3662	North of Mt.Miwa	95

They are well grouped in the range 110-90 m.y. No intrusion-time-gap is observed between the so-called "older" and "younger" granitic rocks in this district. The K-Ar age 115 m.y. on hornblende, is obtained from the gneissose granodiorite which is considered to be the "older" granitic rock. The K-Ar age on hornblende is approximately concordant with the Rb-Sr age 103 m.y. on co-existing biotite. This result also supports the view that no great difference had existed in the time of the emplacement between the "older" and the "younger" granitic rocks. Most of the granitic rocks in this district had intruded successively in the period ranging approximately 110-90 m.y.

The results of the age measurements on mica of the banded gneiss revealed a quite complicated age pattern, compared with that of the granitic rocks which are well converged in the range 110-90 m.y.

The Rb-Sr age on muscovite is always discordant with that of co-existing biotite. One muscovite (R-4309) yielded the apparent Rb-Sr age as large as 231 m.y., when calculated in the customary manner; the usual method of calculation assumes that the isotopic composition of the initial strontium has "normal" strontium isotopic composition, namely Sr^{87}/Sr^{86} = .708.

There is, however, no guarantee that this condition was fulfiled for the banded gneiss which was derived from pelitic sediments. Compared with biotite, muscovite contains a large amount of "normal" strontium as seen in the analytical data, inspite of the fact that no strontium-rich minerals are observed in muscovite by thin section study The high content of "normal" strontium in muscovite samples could not be reduced by further purification procedures. Therefore, it is assumed that muscovite itself contains a large amount of "normal" strontium.

This may indicate that much more strontium had been introduced into muscovite than biotite, when these minerals were formed by recrystallization in metamorphism. The introduced strontium may not have "normal" strontium isotopic composition, but have been enriched in Sr^{87}, because of partial retention of radiogenic Sr^{87} accumulated prior to the metamorphism. It is assumed that the strontium isotope homogenization had not been achieved at the time of the metamorphism.

This assumption may be supported by the following fact: R-4309 and R-4310 were taken from the road cut exposures along the identical road. Two exposures are only a few hundred meters apart. The Rb-Sr ages on biotite of these two samples are 192 m.y. and 107 m.y. respectively.

It may be quite unreasonable to assume that the banded gneiss had experienced two metamorphism which occurred at 192 m.y. and 107 m.y.

This fact may be assigned to the incomplete strontium isotope homogenization at the metamorphism. Of seven Rb-Sr ages on biotite, four of them are well converged to approximately 100 m.y. as is seen in Table 13, which suggests that the banded gneiss had been produced by the 100 m.y. metamorphism.

TABLE 13

The Rb-Sr age of the banded gneiss

Sample	Locality	Mineral	age (m.y.)
R-4005	Takamadoyama	Biotite	101
R-4307	Joryu	Biotite	103
R-4308	Nunobiki	Biotite	108
R-4310	Nunobiki	Biotite	107

This is also compatible with the fact that the granitic rocks in this district had intruded in the period ranging 110-90 m.y.

In the Palaeozoic formation, i.e., Tamba Zone, which is situated in the north of the Ryoke metamorphic terrain, granites which have been known as the "Cretaceous granite" among geologists, develop widely. Yoshizawa et al. (1965a) divided the granites in this region into the following two groups:

1. Hira-Suzuka-Tanokami group
2. Hiei-Mikumo (Shigaraki) group

The granites of group 1. usually accompany many pegmatites, intrude into the Palaeozoic strata discordantly with its structure and give contact metamorphism to the Palaeozoic strata. These granites are typical "granite" which are medium- to coarse-grained and are considered to have intruded at a shallower depth. The granites of group 2. accompany almost no pegmatite and intrude into the Palaeozoic strata, being approximately concordant with its structure and give also contact metamorphism.

These granites are usually adamellitic in their rock phase. A samll amount of hornblende is observed rarely in these granites. These two types of the granites were considered to be of co-magmatic origin. The granites of group 1. may have intruded to a shallower depth at a more or less later stage than the granites of group 2. The depth difference and the emplacement time-gap between these two granites may be small.

On these granites, the age measurements were made by Hayase (1961). The results are as follows:

Rock	Mineral	Rb-Sr	K-Ar	
Hiei granite	biotite	93	90	
Suzuka granite (Yunoyama pegmatite)	muscovite	78	61	(in m.y.)

As to the relation of these "Cretaceous granite" to the granite in the Ryoke metamorphic terrain, the following geological relations have been made known.[34]

1. At Suzuka Pass, Mie Prefecture, mylonitic rocks exist between the Ryoke granite (Yagyu granite) and the Suzuka granite, running approximately N70°E.
2. In the region of the northwest of Ueno City, the Yagyu granite is transitional into the "Cretaceous granite" in its rock facies, through the mylonitic rock which is assumed to be the western extension of the above-mentioned mylonitic rock.

The time of the emplacement of the Hiei granite is almost contemporaneous with the granite in the Ryoke metamorphic terrain (Yagyu granite). Therefore the Hiei-Mikumo (Shigaraki) granite, i.e., the "Cretaceous granite" and the Ryoke granite may be co-magmatic, judging from both geologically and geochronologically. although the depth of the emplacement may be different. The granites of group 1. are of a later stage emplacement than the granites of group 2. and the Ryoke granite.

Conclusion

1. The geology in the western marginal part of the Ryoke metamorphic terrain in the Kinki district is summarized as follows:

This area consists almost entirely of granitic rocks, with only a small amount of metamorphic rocks of sedimentary origin, compared with the eastern part of the terrain which has a good development of the metamorphic rocks of sedimentary origin. The geological structure indicated by gneissose granodiorite and fine-grained granite is monoclinal, dipping northward throughout the western district. The Katsuragi granodiorite which is quite homogeneous in rock facies and carries no inclusions throughout the body, may represent the core part of the metamorphic terrain in the western district. The granodiorite developing in the southern part of this district has suffered shearing to various degrees.

2. With 24 samples of pegmatites, granitic rocks and banded gneisses collected from the Ryoke metamorphic terrain in the Kinki district, mainly from the western part of the terrain, the age measurements were carried out by both the Rb-Sr and K-Ar methods.

The Rb-Sr ages on biotites of the granitic rocks in this district are well converged into 110 m.y - 90 m.y., with several exceptions. The K-Ar age 115 m.y. on hornblende which is approximately concordant with the Rb-Sr age 103 m.y. on co-existing biotite, is obtained on the gneissose granodiorite which was considered to be the "older" granitic rock. These facts suggest that there is no intrusion-time-gap among the granitic rocks and that most of the granitic rocks had been emplaced successively 110 m.y.- 90 m.y. ago.

The quartz diorite which yielded the Rb-Sr age 130 m.y. may have been an intrusion preceding those of the granitic rocks in the Ryoke metamorphic terrain in the Kinki district.

3. The age measurements on biotite and muscovite of seven banded gneiss samples revealed a distinct discordance among them; the Rb-Sr ages on biotite and muscovite have a wide scatter ranging from 231 m.y. to 101 m.y.

The wide scatter of the Rb-Sr ages shows that a complete homogenization in strontium isotope had not been achieved at the time of the metamorphism in these banded gneisses. Judging from the fact that the age of the emplacement of the granitic rocks is considered to be approximately 110 m.y.- 90 m.y., the banded gneiss may have been produced by the 110 m.y.- 90 m.y. metamorphism. The K-Ar age measurements yielded a considerably younger ages than the Rb-Sr ages on them, although a fairly good agreement was obtained among them. The K-Ar age on banded gneiss may represent the time of the granitic activity which occurred 70 m.y.- 60 m.y. ago.

4. The Rb-Sr ages on muscovite, biotite and potassium feldspar of the pegmatites in this district are 90 m.y.- 70 m.y. This means that the metamorphism and plutonism had ended approximately 90 m.y.- 70 m.y. ago in the terrain.

5. As to the relation between the granites in the Ryoke metamorphic terrain and the "Cretaceous granite" in the Tamba Zone, both of the granites are considered to be co-magmatic and in gradual change in their rock facies: The latter may have been emplaced in a shallower depth than the former.

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